

CHAPTER 9

ENERGY DISSIPATORS

Chapter 9 - Energy Dissipators

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9.1 Introduction

9.1.1 Overview

The concentration of flow at culverts often results in increased velocities with a corresponding increase in erosion potential. If unchecked, the increased erosion potential can cause damage or failure of structures and the highway. To protect the culvert and adjacent areas, it is sometimes desirable to use an energy dissipator.

9.1.2 Definition

Energy dissipators are devices designed to reduce culvert outlet velocities to acceptable limits.

9.1.3 Purpose

This chapter provides:

- Criteria for selecting type of energy dissipator
- Design procedure for various types of energy dissipators including
 - weir-block energy dissipator
 - stilling basin
 - drop structures
 - impact basins, USBR Type VI
- Design procedures for selected types of dissipators that are based on FHWA Hydraulic Engineering Circular Number 14 (HEC 14) "Hydraulic Design of Energy Dissipators for Culverts and Channels," September 1983, revised in 1995.
- Results of analysis using the HY8 software for stilling basins, drop structures, and USBR Type VI impact basins.

9.1 Introduction (continued)

9.1.4 Symbols

Table 9-1 Symbols, Definitions And Units

<u>Symbol</u>	<u>Definition</u>	<u>Units</u>
A	Cross sectional area	ft ²
A _o	Area of flow at culvert outlet	ft ²
d _E	Equivalent depth at brink	ft.
d _o	Normal flow depth at brink	ft.
D	Height of culvert	ft.
D ₅₀	Mean diameter of riprap	in.
DI	Discharge Intensity Modified	-
Fr	Froude Number	-
H	Height of weir block	ft.
h _s	Depth of dissipator pool	ft.
L	Length of culvert	ft.
L _B	Overall length of basin	ft.
L _S	Length of dissipator pool	ft.
Q	Rate of discharge	ft ³ /sec
S _o	Slope of streambed	ft./ft.
TW	Tailwater depth	ft.
V _d	Velocity downstream	ft./sec
V _L	Velocity -- (L) feet from brink	ft./sec
V _o	Normal velocity at brink	ft./sec
W _o	Diameter or width of culvert	ft.
W _S	Width of scour hole	ft.
Y _o	Depth of flow at brink	ft.
Y ₂	Sequent Depth (Alternate Depth)	ft.

9.2 Design Goals

9.2.1 Overview

The goal of using energy dissipators is to manage the effects of high velocity by providing a structure that will reduce the outlet velocity of the design flow to an acceptable value. The desired level is within 120% of the average main channel velocity. The reduction of velocity may be accomplished by a change in direction (drop structure), an increase in the flow resistance (rip-rap mattress), or by forcing a change in the flow from supercritical to subcritical (weir block). Changing flow conditions from supercritical to subcritical will require the formation of a hydraulic jump.

9.2.2 Selection Criteria

The dissipator type selected for a site must be appropriate to the location. Natural scour holes may need to be estimated to determine the value of providing additional protective measures. The selection of the means to accomplish a change in flow conditions is affected by the flow conditions in the downstream channel. Discussed in this chapter are natural scour holes, hydraulic jumps using weirs or stilling basins, and USBR Type VI Impact Basins.

The hydraulic jump is a means to accomplish a reduction in velocity. If the downstream flow results in low tail water, some artificial means is used to create the additional tailwater necessary to force a hydraulic jump. For low Froude numbers, i.e. less than 3, this may be accomplished by using a “dam” or weir or dropping the outlet apron. For culverts 48” or larger, with flow less than 150 cfs, a weir block and apron at the end of the wing wall may achieve the desired results. For situations where the approaching subcritical flow must be dropped some distance, a straight drop stilling basin may be the appropriate solution. For supercritical flows, a sloping drop stilling basin may be necessary. Other situations may require the use of baffles.

Table 9-2 Dissipator Selection Criteria

<u>Approach Flow</u>	<u>Downstream Flow</u>	<u>Dissipator</u>	<u>Debris Restrictions¹</u> <u>Floating / Boulders</u>		<u>Tailwater</u> <u>Required.</u>
Subcritical	Subcritical	Straight Drop	M	L	Yes
Supercritical, Fr=1 to 4	Supercritical	Weir Block	M	L	No
Fr=1 to 4	Subcritical	Abrupt Rise	M	L	Yes
Fr=1.7 to 17	Subcritical	SAF stilling basin	M	L	Yes
Fr=2.5 to 4.5	Subcritical	USBR Type VI	M	L	No

NOTE 1: Debris Restrictions: M-Medium, L-Large

9.2 Design Goals (continued)

9.2.3 Design Considerations

Debris

The occurrence of debris shall be considered in the design of energy dissipators. Debris control shall be designed using Hydraulic Engineering Circular No. 9, "Debris-Control Structures" and shall be considered:

- where potential for large debris exists, and
- where clean out access is limited.

Design Flood Frequency

The flood frequency used in the design of the energy dissipator device is usually the same flood frequency used for the culvert or channel design. The use of a greater frequency may be appropriate if justified by documented special site conditions, such as downstream concerns.

Maximum Dissipator Exit Velocity

The dissipator exit velocity should be within 120% of the average main channel velocity.

Tailwater Relationship

The hydraulic conditions downstream shall be evaluated to determine a tailwater depth and the maximum velocity for the range of discharges to be considered.

Large water bodies shall be evaluated using the water elevation that has the same frequency as the design flood for the culvert and/or channel if events are known to occur concurrently, statistically dependent. If statistically independent, evaluate the joint probability of flood magnitudes and use a likely combination.

Safety Considerations

Traffic shall be protected from external energy dissipators by locating them outside the appropriate "clear zone" distance per AASHTO Roadside Design Guide or shielding them with a traffic barrier.

9.2 Design Goals (continued)

9.2.4 Design Options

Weep Holes

If weep holes are used to relieve uplift pressure, they shall be designed in a manner similar to underdrain systems.

Culvert Outlet Type

In choosing a dissipator, the selected culvert end treatment has the following implications:

- Culvert ends which are projecting or mitered to the fill slope offer no outlet protection.
- Aprons do not reduce outlet velocity. They shall not protrude above the normal streambed elevation.

9.2.5 Related Designs

Culvert

The culvert shall be designed considering the site requirements. If it is determined that energy dissipation is needed, the design shall be reviewed to ascertain any impacts that can be mitigated by changes in the culvert design (Chapter 8 Culverts). The culvert design shall include computation of outlet velocity before the final outlet protection is designed.

Downstream Channel

The downstream channel protection shall be designed concurrently with dissipator design (Chapter 7 Channels).

9.3 Design Philosophy

9.3.1 Overview

The energy dissipator design approach used in this chapter is discussed in the following sections:

9.3.2 Alternative Analysis

Choose alternatives, which satisfy:

- Topography, and
- design policies and criteria.

Analyze alternatives for:

- environmental impact, such as need for animal passage
- hydraulic efficiency, and
- risk and cost.

Select an alternative that best integrates engineering, economic and environmental considerations:

The chosen dissipator should meet the selected structural and hydraulic criteria and should be based on:

- construction and maintenance costs,
- risk of failure,
- property damage,
- traffic safety,
- environmental and aesthetic considerations, and
- land use requirements.

9.3.3 Design Methods

The designer has to determine:

- whether to mitigate or monitor erosion problem,
 - design conditions of local scour and/or channel degradation, and
 - the type of energy dissipator to be used
- .

9.3 Design Philosophy (continued)

9.3.3 Design Methods (continued)

9.3.3.1 Types Of Scour

Local Scour

Local scour is the result of high velocity flow at the culvert outlet and extends only a limited distance downstream.

Channel Degradation

Channel degradation may proceed in a fairly uniform manner over a long length or may be evident in one or more abrupt drops (headcuts) progressing upstream with every runoff event.

- It should be investigated as an essential part of the site investigation.
- It should be mitigated and addressed in the initial construction (see Channels, Chapter 7).
- It is usually mitigated with drop structures.

9.3.3.2 Dissipator Types

The dissipator types discussed include:

- Weir block hydraulic jump (Section 9.6).
- USBR Type VI impact basin (Section 9.7).
- Saint Anthony Falls stilling basin, SAF (Section 9.8).
- Straight Drop Stilling Basin (Section 9.9)

Other dissipator types are discussed in the FHWA HEC 14 "Hydraulic Design of Energy Dissipators for Culverts and Channels," September 1985.

- Riprap.
- CSU rigid boundary.
- Contra Costa.
- Hook.
- USBR Type II.
- USBR Type III
- USBR Type IV.

9.3 Design Philosophy (continued)

9.3.3 Design Methods (continued)

9.3.3.3 Computational Methods

Charts

Charts required for the design of USBR Type VI impact basin, SAF stilling basin, and Straight Drop stilling basins are included in this Chapter. Charts required for the design of other types of energy dissipators are found in HEC 14.

Computer Software

HY-8 (FHWA Culvert Analysis Software) Version 4.1 or greater, contains an energy dissipator module which can be used to analyze most types of energy dissipators in HEC 14.

9.4 Design Equations

9.4.1 General

An exact theoretical analysis of flow at energy dissipators is extremely complex because the following approaches are required:

- analyzing non-uniform and rapidly varying flow,
- applying energy and momentum balance,
- determining where a hydraulic jump will occur, and
- applying the results of hydraulic model studies.

9.4.2 Design Approach

The design procedures presented in this Chapter are based on the following:

- Discussions regarding hydraulic jumps (Chow)
- Model studies were used to calibrate the equations and charts for scour hole estimating and energy dissipator design.
- HEC 14 (revised version, 1995) is the base reference and contains explanation of the equations and procedures used in this Chapter for stilling basins, drop structures, and riprap basins.

9.4 Design Equations (continued)

9.4.3 Flow Conditions

The approach flow condition establishes the hydraulic parameters for design of energy dissipators.

Depth (ft.), d_o .

- Is the depth at the beginning of the energy dissipator
- The normal depth assumption should be reviewed and a water surface profile calculated if $L < 50 d_o$.
- The brink depth and not critical depth (see HEC 14 for curves) should be used for mild slopes and low tailwater.

Equivalent Depth (ft), d_E

$$d_E = (A_o/2)^{0.5}$$

Equivalent depth is an artificial depth that is calculated for culverts that are not rectangular so that a reasonable Fr can be determined.

Area (ft²), A_o .

The cross-sectional area of flow at the approach section should be calculated using (d_o).

Velocity (ft/sec), V_o

The velocity at the approach to the dissipator should be calculated as follows:

$$V_o = Q/A_o \tag{9.1}$$

Where: Q= discharge, cfs

Froude Number, Fr

The Froude number is a flow parameter that has traditionally been used to design energy dissipators and is calculated using:

$$Fr = V_o / [(g d_o)^{0.5}] \tag{9.2}$$

Where: g = acceleration of gravity, 32.2 ft/sec²

9.4 Design Equations (continued)

9.4.3 Flow Conditions (continued)

Sequent Depth, (Alternate depth), ft

The sequent depth (alternate depth) is the depth to which supercritical flow changes in a hydraulic jump. It has the same energy at the subcritical flow energy condition.

$$Y_1 + V_1^2/2g = Y_2 + V_2^2/2g$$

$$Y_2 = (Y_1/2) * [(1 + 8Fr^2)^{0.5} - 1] \quad (9.3)$$

Where: Y_1 = initial depth of water, ft.

Y_2 = sequent depth of jump, ft.

Fr_1 = Froude number of flow entering basin based on d_1

Discharge Intensity, DI_c

Discharge Intensity is a flow parameter similar to Fr that is used for circular culverts of diameter (D) that are flowing full.

$$DI_c = Q/(g^{0.5} D^{2.5}) \quad (9.4)$$

Discharge Intensity Modified, DI

Referring to Chapter V, HEC 14, revised version 1995, the Modified Discharge Intensity, DI , for all culvert shapes are:

$$DI = Q/(g^{0.5} R_c^{2.5}) \quad (9.5)$$

Where: Q = discharge, cfs

A_c = culvert area, ft^2

P_c = culvert perimeter, ft

$R_c = (A_c/P_c)$

See Appendix for table of diameter, area, perimeter, and hydraulic radius.

9.5 Scour Hole Estimation

9.5.1 Overview

Scour holes may form at the outlets of culverts or at channel drops. Chapter V of HEC 14 (revised version, 1995) contains a procedure for estimating scour hole geometry for culvert outlets based on soil, flow data and culvert geometry. The US Bureau of Reclamation has procedures for estimating the scour below channel drops.

9.5.2 Outlet Scour Prediction

It is intended that this scour prediction procedure be used along with the maintenance history and site reconnaissance information for determining energy dissipator needs. Only scour hole in cohesionless material will be discussed in this Chapter. For scour hole in cohesive soil, the designer should refer to Chapter V, HEC 14. The results of the tests made by the US Army Waterways Experiment Station, Vicksburg, Mississippi indicate that the scour hole geometry varies with the tailwater conditions. The maximum scour geometry occurs at tailwater depths less than half the culvert height. The maximum depth of scour, d_s , occurs at a location approximately $0.4L_s$ downstream of the culvert, where L_s is the length of the scour.

9.5.2.1 Culvert Outlet Scour - Equations

The following empirical equations from the reference **Scour at Culvert Outlets in Mixed Bed Materials** (Ruff, J.F., S.R. Abt, C. Mendosa, A. Shaikh, and R. Kloberdanz.). These equations define the relationship between the culvert discharge intensity, time and the length, width, depth and volume of the scour hole for the maximum or extreme scour case.

$$(d_s/R_c), (W_s/R_c), (L_s/R_c) = C_s C_h [\alpha/\sigma^{0.33}] [DI]^\beta [t/316]^\theta \quad (9.6)$$

$$d_s, W_s, \text{ or } L_s = F_1 F_2 F_3 R_c \quad (9.7)$$

$$F_1 = C_s C_h \left(\frac{\alpha}{\sigma^{1/3}} \right)$$

$$F_2 = \left(\frac{Q}{\sqrt{g} R_c^{2.5}} \right)^\beta = (DI)^\beta$$

$$F_3 = \left(\frac{t}{316} \right)^\theta$$

9.5 Scour Hole Estimation (continued)

9.5.2 Outlet Scour Prediction (continued)

Where: d_s = maximum depth of scour hole, ft

L_s = length of scour hole, ft

W_s = width of scour hole, ft

t = 30 min or the time of concentration, if longer

R_c = hydraulic radius of the flow at the exit of the culvert

σ = material standard deviation, generally, $\sigma = 2.10$ for gravel and 1.87 for sand

a, b, Q, C_s and C_h are coefficients, as shown in Table 9-2

F_1 , F_2 and F_3 are factors to aid the computation

Table 9-3 Scour Hole Coefficients

A. Coefficient for Culvert Outlet Scour - Cohesionless Materials

	a	b	Q
Depth, d_s	7.96	0.26	0.09
Width, W_s	26.42	0.62	0.06
Length, L_s	64.54	0.56	0.17
Volume, V_s			

B. Coefficient C_s for Outlets Above the Bed

H_s	Depth	Width	Length	Volume
0	1.00	1.00	1.00	1.00
3.28	1.22	1.51	0.73	1.28
6.56	1.26	1.54	0.73	1.47
13.12	1.34	1.66	0.73	1.55
H_s is the height above bed in pipe diameters, ft				

9.5 Scour Hole Estimation (continued)

9.5.2.1 Culvert Outlet Scour – Equations (continued)

C. Coefficient C_h for Culvert Slope

Slope %	Depth	Width	Length	Volume
0	1.00	1.00	1.00	1.00
2	1.03	1.28	1.17	1.30
5	1.08	1.28	1.17	1.30
>7	1.12	1.28	1.17	1.30

9.5.2.2 Culvert Outlet Scour – Design Procedure

The following design procedures are intended to provide a convenient and organized method for designing energy dissipators. The designer should be familiar with all the equations in section 9.4 before using these procedures. In addition, application of the following design method without an understanding of hydraulics can result in an inadequate, unsafe, or costly structure.

Step 1 Assemble Site Data And Project File

- a. See design file for site survey.

Step 2 Determine Hydrology, Select Design Q

See design file.

- b. Select flood frequency.
- c. Determine Q.

Step 3 Design Downstream Channel

- a. Determine channel slope, cross section, normal depth and velocity.
- b. Check bed and bank materials stability.

Step 4 Design Culvert

See design file and obtain: design discharge, outlet flow conditions (velocity and depth), culvert type (size, shape and roughness), culvert slope and performance curve, if necessary.

Step 5 Summarize Data On Design Form

- a. Enter data from steps 1-4 into Figure 9-1: Scour Hole Estimation Form.

Step 6 Estimate Scour Hole Size

- a. Enter input for scour equation on Figure 9-1.
- b. Calculate d_s , W_s , L_s , using equations 9.6 or 9.7

9.5 Scour Hole Estimation (continued)

9.5.2.2 Culvert Outlet Scour – Design Procedure (continued)

Step 7 Determine Need For Dissipator

An energy dissipator is needed if:

- a. the estimated scour hole dimensions exceed the allowable right-of-way, undermines the culvert cutoff wall, or presents a safety or aesthetic problem;
- b. downstream property is threatened; or
- c. V_o is greater than $150 \%V_d$.

Step 8 Select Design Alternative

- a. Calculate Froude number, Fr .
- b. Choose energy dissipator types.
 - If $Fr < 3$, design a weir block hydraulic jump basin, a riprap basin or a USBR Type VI. These types are recommended only if $Q < 500 \text{ ft}^3/\text{s}$ for each barrel and little debris is expected. If these are not acceptable or economical, try other dissipators in HEC 14.
 - If $Fr > 3$, design a SAF stilling basin.

Step 9 Design Dissipators

Use the following design procedures and charts:

- Section 9.6 for the weir block hydraulic jump basin.
- Section 9.7 for the USBR Type VI impact basin.
- Section 9.8 for the SAF basin.

Step 10 Design Riprap Transition

- a. Most dissipators require some apron adjacent to the basin exit.
- b. The length of apron protection can be judged based on the difference between V_o and V_d . See HEC 14 for length required for size and length of protection needed.

Step 11 Review Results

- a. If preferred energy dissipator affects culvert hydraulics, return to step 4 and calculate culvert performance.
- b. If debris-control structures are required upstream, consult HEC 9.

Step 12 Documentation

- a. See Documentation Chapter.

9.5 Scour Hole Estimation (continued)

9.5.2 Outlet Scour Prediction (continued)

Scour Hole Estimation Form			
Project Name _____	Project No. _____		
Subject _____	Page _____ of _____		
By _____	Date _____	Checked By _____	Date _____

Data Summary		
Parameter	Approach Channel	Downstream Channel
Station		
Control		
Type		
Height, D		
Width, B		
Length, L		
Material		
Manning's n		
Side Slope		
Slope		
Discharge		
Depth, d		
Velocity, V		
Froude No.		
Flow Area		

Equation Input Data	
Factor	Value
Discharge, Q cfs	
Flow Area, A, Ft ²	
Wetted Perimeter, Ft	
Hydraulic Radius, R=A/P	
Discharge Intensity	
Time of Concentration, t, min	

Scour Equations			
$(d_s/R_c), (W_s/R_c), (L_s/R_c) = C_s C_h [a/s^{0.33}] [DI]^b [t/316]^\theta$ $= F_1 F_2 F_3 R_c$			
Scour Computation			
Factor	Depth	Width	Length
Alpha, a			
Beta, b			
Theta, θ			
$F_1 = C_s C_h [a/s^{0.33}]$			
$F_2 = [DI]^b$			
$F_3 = [t/316]^\theta$			
Scour			

Figure 9-1 Scour Estimation Form

9.5 Scour Hole Estimation (continued)

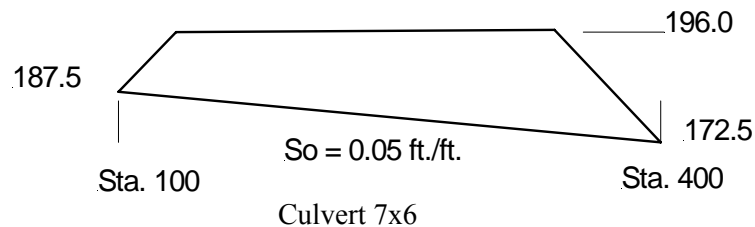
9.5.2 Outlet Scour Prediction (continued)

9.5.2.3 Design Example

The following example uses a 7x6 culvert. This is not a standard ADOT culvert. Its use here is not to be understood as endorsement of using this size of culvert.

Step 1 Assemble Site Data And Project File

- a. Site survey - The culvert project file contains site and location maps; roadway profile and embankment cross sections. Site visit notes indicate no sediment or debris problems and no nearby structures.



- b. Studies by other agencies - none.
- c. Environmental, risk assessment shows no problems.
- d. Design criteria:
 - 50-year frequency for design

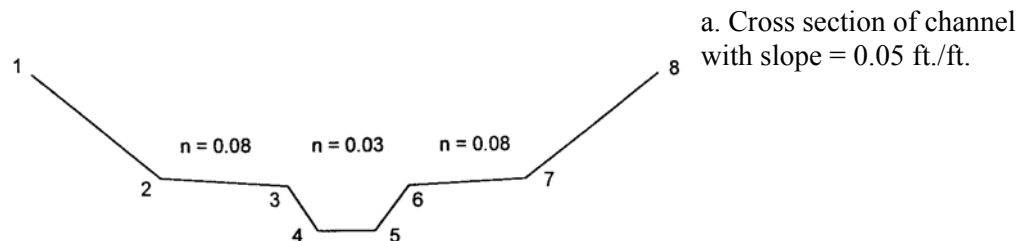
Step 2 Determine Hydrology

From project file:

- $Q_{50} = 400 \text{ cfs}$
- $Q_{100} = 500 \text{ cfs}$

Select Design Q: Use $Q_{50} = 400 \text{ cfs}$

Step 3 Design Downstream Channel



9.5 Scour Hole Estimation (continued)

9.5.2.3 Design Example (continued)

Step 3 Design Downstream Channel (continued)

Point	Station, ft	Elevation, ft
1	12	180
2	22	175
3	32	174.5
4	34	172.5
5	39	172.5
6	41	174.5
7	51	175
8	61	180

b. Rating Curve for Channel

Calculating normal depth yields:

Q (cfs)	TW (ft)	V (ft/sec)
100	1.4	11
200	2.1	14
300	2.5	16
400	2.8	18
500	3.1	19

c. For $Q_{50} = 400$ cfs, with $V_{50} = 18$ ft/sec the 3-in gravel material which makes up the channel boundary is not stable and riprap is needed (see Channel, Chapter 7) for a transition.

Step 4 Design Culvert

A 7x6 RCB with a beveled entrance on a slope of 0.05 ft/ft was the selected design. The FHWA HY8 program showed that this culvert is operating at inlet control and has the following hydraulic behavior:

Q (cfs)	HW _i (ft)	V _o (ft/sec)
$Q_{50} = 400$	7.6	32
$Q_{ot} = 430$	8.5	
$Q_{100} = 500$	8.6	34

Step 5 Summarize Data On Design Form

See Figure 9-2.

Step 6 Determine Size of Scour Hole

The size of the scour hole is determined using equations 9.5 and 9.6. For channel with gravel bed, the standard deviation of the material, σ is 2.10. Table 9-2 shows that the value of $C_S = 1.00$ and $C_h = 1.08$. See Figure 9-2 for a summary of the computation.

9.5 Scour Hole Estimation (continued)

9.5.2.3 Design Example (continued)

Step 7 Determine Need For Dissipator

The scour hole dimensions are excessive, and since $V_o = 32$ ft/sec is much greater than $V_d = 18$ ft/sec, an energy dissipator is needed.

Step 8 Review Results

The downstream channel conditions are matched by the dissipator.

Step 9 Documentation

- a. See Documentation Chapter 5.
- b. Include computations in the culvert report or file.

9.5 Scour Hole Estimation (continued)

9.5.2 Outlet Scour Prediction (continued)

Scour Hole Estimation Form			
Project Name__ Design Example_____		Project No._ADT064_____	
Subject _____ Scour Hole Example_____		Page _1_ of _____	
By _____	Date _____	Checked By _____	Date _____

Data Summary		
Parameter	Approach Channel	Downstream Channel
Station	125+50	4+00
Control	Inlet	Supercritical
Type	CBC	Natural
Height, D	6	7.5'
Width, B	7	29'
Length, L	300	---
Material	Concrete	Gravel
Manning's n	0.012	0.03 & 0.08
Side Slope	---	1:1
Slope	0.05	0.05
Discharge	400	40
Depth, d	1.8'	2.8'
Velocity, V	32 ft/sec	18 ft/sec
Froude No.	4.2	1.9
Flow Area	12.5	22.2

Equation Input Data	
Factor	Value
Discharge, Q cfs	400
Flow, A, Ft ²	42
Wetted Perimeter, Ft	26
Hydraulic Radius, R=A/P	1.62
Discharge Intensity	1.32
Time of Concentration, t, min	30

Scour Equations			
$(d_s/R_c), (W_s/R_c), (L_s/R_c) = C_s C_h [a/s^{0.33}] [DI]^{\beta} [t/316]^{\theta}$ $= F_1 F_2 F_3 R_c$			
Scour Computation			
Factor	Depth	Width	Length
Alpha, a	7.6	26.42	64.54
Beta, b	0.26	0.62	0.56
Theta, Q	0.09	0.06	0.17
$F_1 = C_s C_h [a/s^{0.33}]$	8.6	31.4	75.4
$F_2 = [DI]^b$	0.8	0.9	0.7
$F_3 = [t/316]^Q$			
Scour	7	28	53

**Figure 9-2 Scour Hole Estimation Form
Example Problem**

9.5 Scour Hole Estimation (continued)

9.5.2.3 Design Example (continued)

Computer Output

The scour hole geometry can also be computed by using the "Energy Dissipators" module of the FHWA microcomputer program HY-8, Culvert Analysis, Version 4.1 or later. A hardcopy of the output of module is as shown below. The dimensions of the scour hole computed by the HY-8 program are pretty close to the values calculated in the previous section.

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0			
CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
06-04-1997	10:56:51	CHPTR11A	06-04-1997

CULVERT AND CHANNEL DATA	
CULVERT NO. 1	DOWNSTREAM CHANNEL
CULVERT TYPE: 7.0 x 6.0 BOX	CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 300.0 FT	BOTTOM WIDTH = 7.0 FT
NO. OF BARRELS = 1.0	TAILWATER DEPTH = 2.8 FT
FLOW PER BARREL = 400 CFS	TOTAL DESIGN FLOW = 400 CFS
INVERT ELEVATION = 172.5 FT	BOTTOM ELEVATION = 172.5 FT
OUTLET VELOCITY = 31.3 FPS	NORMAL VELOCITY = 17.5 FPS
OUTLET DEPTH = 3.2 FT	

SCOUR HOLE GEOMETRY AND SOIL DATA	
LENGTH = 91.4 FT	WIDTH = 49.3 FT
DEPTH = 9.2 FT	VOLUME = 4609.7 CU FT
MAXIMUM SCOUR OCCURS 36.6 FT DOWNSTREAM OF CULVERT	
SOIL TYPE: NONCOHESIVE	
SAND SIZES:	
D16 = 8 mm	
D50 = 14 mm	
D84 = 18 mm	

9.5 Scour Hole Estimation (continued)

9.5.3 Channel Drop Scour

The “Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona”, 1989 presents a discussion on scour below drop structures. The following paragraphs are a summary of that information. Scour below channel drops, such as grade control structures, is a special case of local scour. Where a drop consist of a free, unsubmerged overfall, the depth of scour shall be computed as follows:

$$Z_{lsf} = 1.32 q^{0.54} H_t^{0.225} - TW \quad (9.8)$$

Where

Z_{lsf} = Depth of local scour due to free-overfall drop measured below the streambed surface downstream of the drop, in ft.

q = Discharge per unit width of the channel bottom, in cfs.

H_t = Total drop in head, measured from the upstream energy grade line to the downstream energy grade line, in feet,

TW = Tailwater depth, in feet.

When the drop is submerged the depth of scour shall be computed as

$$Z_{lss} = 0.581 q^{0.667} (h/Y)^{0.411} [1-(h/Y)]^{-0.118} \quad (9.9)$$

Where: $h/Y \leq 0.99$ and

Z_{lss} = Depth of scour due to submerged drop measured from the downstream streambed surface, in feet.

q = Discharge per unit width of the channel bottom, in cfs.

h = Drop height in ft.

Y = Downstream depth of flow, ft

If h/Y is greater than 0.85, the predicted scour should also be computed using the free drop equation. The smaller of the two values thus computed should be used.

The longitudinal extent of a scour hole for either free or submerged overfall is calculate as:

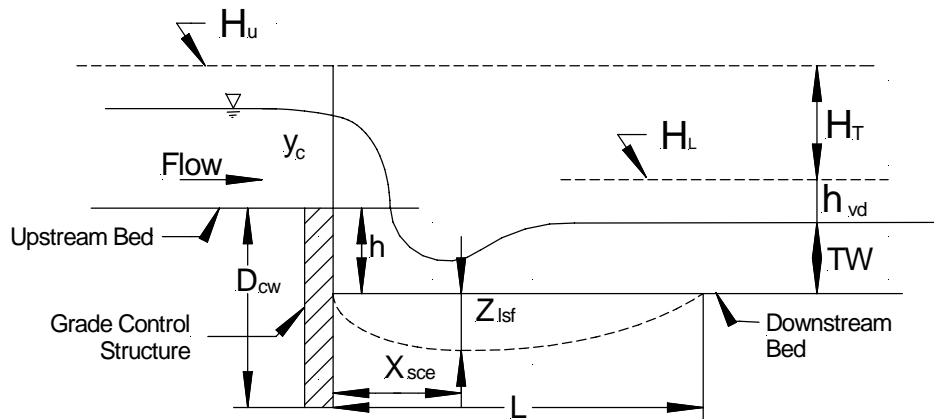
$$x_{sce} = 6.0 * Z_{lsf} \text{ or } 6.0 * Z_{lss} \quad (9.10)$$

$$L_s = 12.0 * Z_{lsf} \text{ or } 12.0 * Z_{lss} \quad (9.11)$$

Bank protection toe-downs downstream of grade control structures shall extend to the computed depth of scour for a distance equal to x_{sce} beyond the grade-control structure. The toe-down shall then taper to the normal toe-down depth at the distance L_s . Note that L_s includes x_{sce} .

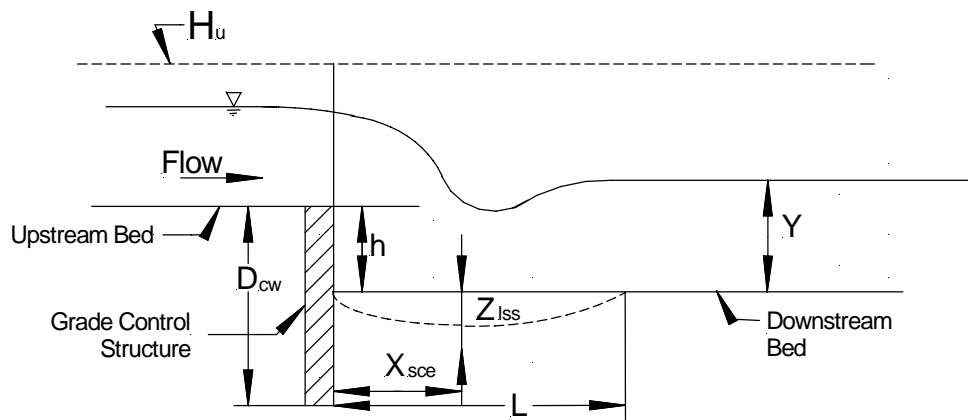
9.5 Scour Hole Estimation (continued)

9.5.3 Channel Drop Scour (continued)



(a)

Scour below Free Outfall



(b)

Scour below Submerged Outfall

Figure 9-3 Scour below outfall: (a) Free (b) Submerged

9.6 Weir Block Basin

9.6.1 Overview

The weir block basin design is based on creating a hydraulic jump by placing an obstruction to the flow. The goal is a velocity reduction that meets the requirements for minimal erosion. Following are the principal features of the basin:

- Using a weir block of at least height Z : that forces a hydraulic jump.
- Constructing the floor at either the culvert outlet or depth of Z below the invert, where Z is the depth necessary to accomplish the required Y_2 .
- Sizing the length of the basin to the weir block equal to $5*Y_2$.
- Providing a splash apron of length equal to the greater of L_b (equation 9.10) or 6'.
- Layout details are shown on Figure 9-4a or 9-4b.

Low tailwater, $Y_3 < Y_c$

Downstream Flow is supercritical

- A weir block may be sufficient: the critical velocity over the weir will be lower than the downstream velocity.

Medium Depth Tailwater, $Y_c < Y_3 < Y_2$

Have a choice of using a small sill to create hydraulic jump or a weir block to force critical depth.

For any sill height, a minimum Froude number is necessary, otherwise it acts as a weir.

$$Z \leq (F^{5/3})/6, \text{ maximum sill height for raised step behavior.}$$

High Tailwater, $Y_3 > Y_2$

Flow will rise to tailwater depth, Y_3 , an abrupt rise may be used to control the location of the jump.

9.6.2 Design Procedure : Weir Block

Step 1 Determine Input Flow parameters: (Q , approach depth, and approach velocity)

d_o or d_E , V_o , Fr at the culvert outlet (d_E = the equivalent depth at the brink = $(A/2)^{0.5}$).
Calculate approach Froude number.

Step 2 Determine downstream conditions: (depth, Y_3 and velocity)

Calculate downstream Froude number

9.6 Weir Block Basin (continued)

9.6.2 Design Procedure (continued)

SUPERCritical FLOW

If downstream flow is supercritical, then the only need is to create a weir condition where flow over weir is at critical depth: this will reduce the velocity to less than the downstream velocity.

Step 3 Determine

- a. Y_2 , the alternate depth

$$Y_2 = (Y_1/2) * [(1 + 8Fr^2)^{0.5} - 1] \quad (9.3)$$

Step 4 Size Basin

- a. Determine length of the jump, L_j .

$$L_j = 5 * Y_2 \text{ minimum.} \quad (9-12)$$

Check L versus culvert apron length. Is it appropriate to locate weir block on or at end of apron. If length of jump is greater than apron length, add wire-tied apron.

- b. B , the width of the weir block perpendicular to flow. Use an expansion ration of $1/(3*Fr)$ from culvert end. Allow 1' to 2' of open area for outflow of low flows. Place weir block perpendicular to flow.
- c. For width B , determine the unit discharge over the weir block and critical depth, Y_c .
- d. Determine height required, Z ,

$$Z = Y_2 - Y_c. \quad (9-13)$$

If Z is greater than $(F^{5/3})/6$, then the flow is analyzed as flow over a weir.

If Z is less than $(F^{5/3})/6$, then the flow is analyzed for an abrupt rise.

- e. Determine V_B

- Basin exit depth, d_B = critical depth at basin exit.
- Basin exit velocity, $V_B = Q/(W_B)(d_B)$.
- Compare V_B with the average normal flow velocity in the natural channel, V_d .

Step 5 Determine length of downstream apron, L_B .

$$L_B = 4.3 * H * (q^2 / (gZ^3))^{0.27} \text{ or} \quad (9-14)$$

$$L_B = 6 \text{ feet minimum.}$$

9.6 Weir Block Basin (continued)

9.6.2 Design Procedure (continued)

SUBCRITICAL FLOW

If downstream flow is subcritical, then the need is to create a condition where a hydraulic jump occurs: the flow over the end block weir will be subcritical.

Step 3 Determine approach condition: Y_1, V_1, Fr_1 .

This is based on the width at the upstream end of the energy dissipator. Can locate beginning of dissipator at the headwall of the culvert or at the end of the apron and wingwalls. If using the location at the headwall, then B is the culvert width, or equivalent width for non-rectangular culverts. If using the end of apron, may need to recalculate the hydraulic parameters based on a flare related to the Froude number.

Step 4 Size Basin

a. Y_2 , the alternate depth

$$Y_2 = (Y_1/2) * [(1 + 8Fr^2)^{0.5} - 1] \quad (9.3)$$

b. Determine length of the jump, L_j .

$$L_j = 5 * Y_2 \text{ minimum.} \quad (9-12)$$

Check L versus culvert apron length. Is it appropriate to locate an abrupt rise at end of apron. If the length of jump is greater than apron length, add wire-tied apron.

d. Determine height required, Z ,

$$Z = Y_2 - TW \quad (9-15)$$

If Z is greater than $(F^{5/3})/6$, then the flow is analyzed as flow over a weir.

If Z is less than $(F^{5/3})/6$, then the flow is analyzed for an abrupt rise.

e. Determine V_B

- Basin exit depth, TW = Tailwater depth at basin exit.
- Basin exit velocity, $V_B = Q/(W_B)(TW)$.
- Compare V_B with the average normal flow velocity in the natural channel, V_d .

Step 5 Determine length of downstream apron, L_B .

$$L_B = 6 \text{ feet minimum.}$$

9.6 Weir Block Basin (continued)

9.6.3 Design Example

SUPERCritical FLOW

Given:

2-10x4 box culvert, 0° degree skew with a discharge, Q, of 204 cfs and at a slope of 0.0303
Channel is trapezoidal with 10 feet bottom width and 1.5:1, side slopes, Manning's $n=0.035$,
slope=0.0303. Consider weir block at end of concrete apron.

Step 1 Determine Input Flow parameters:(Q, approach depth, and approach velocity)

d_o or d_E , V_o , Fr at the culvert outlet (d_E = the equivalent depth at the brink = $(A/2)^{0.5}$).
 $Y_1=0.65$ ft, $V_1=15.6$ ft./sec.

Calculate approach Froude number.

$Fr=3.39$

Step 2 Determine downstream conditions:(depth, Y_3 and velocity)

$Y_3=1.77$ ft, $V_3=9.10$ ft./sec.

Calculate downstream Froude number

$Fr=1.33$, downstream flow is supercritical, use a weir block.

Step 3 Determine Alternate Depth

Y_2 , the alternate depth

$Y_2=2.83$ ft., less than height of box.

Step 4 Size Basin

a. Determine length of the jump, L_j .

$L_j = 5*Y_2$ minimum.

$L_j = 5*(2.83)=14.2$ ft. Length of culvert apron=11.5 ft. Since Y_2 is less than height of box, locate weir block at end of apron. Therefore expansion length=11.5 ft.

b. B, the width of the weir block perpendicular to flow. Use an expansion ration of $1/(3*Fr)$ from culvert end.

$$B' = B + 2 * L_e / (3 * F) = 20.83 + \frac{2(11.5)}{3(3.39)}$$

$B'=22.3$, use $B'=24$ Ft.

9.6 Weir Block Basin (continued)

9.6.3 Design Example (continued)

SUPERCritical FLOW (continued)

Step 4 Size Basin (continued)

c. For width 'B', determine the unit discharge over the weir block, critical depth, Y_c , and velocity V_c .

$$q=Q/B'=204/24= 8.5 \text{ cfs}$$

$$Y_c=1.31 \text{ ft.}$$

d. Determine V_B

- Basin exit depth, d_B = critical depth at basin exit.=1.31 Ft.
- Basin exit velocity, $V_B = Q/(W_B)(d_B).$ =(204)/(24*1.31)=6.5 ft/sec
- Compare V_B with the average normal flow velocity in the natural channel, V_d .

$$V_d=9.10 \text{ ft/sec.}$$

$$V_B < V_d \text{ ok.}$$

e. Determine height of block required, Z ,

$$Z=Y_2 - Y_c.$$

$$Z=2.83-1.31=1.52 \text{ ft., use 2 ft.}$$

If Z is greater than $(F^{5/3})/6$, then the flow is analyzed as flow over a weir.

If Z is less than $(F^{5/3})/6$, then the flow is analyzed for an abrupt rise.

$$(F^{5/3})/6=1.28, \quad Z > (F^{5/3})/6, \text{ therefore weir flow condition}$$

Step 5 Determine length of downstream splash apron, L_a .

$$L_a = 4.3 * Z * (q^2 / (g Z^3))^{0.27} = 4.3 * (2) * (8.5)^2 / \{ (32.2 * (2.0)^3) \}^{0.27} = 6.1 \text{ ft, or}$$

= 6 feet, minimum . USE 6' wire-tied apron.

9.6 Weir Block Basin (continued)

9.6.3 Design Example (continued)

SUPERCritical FLOW (continued)

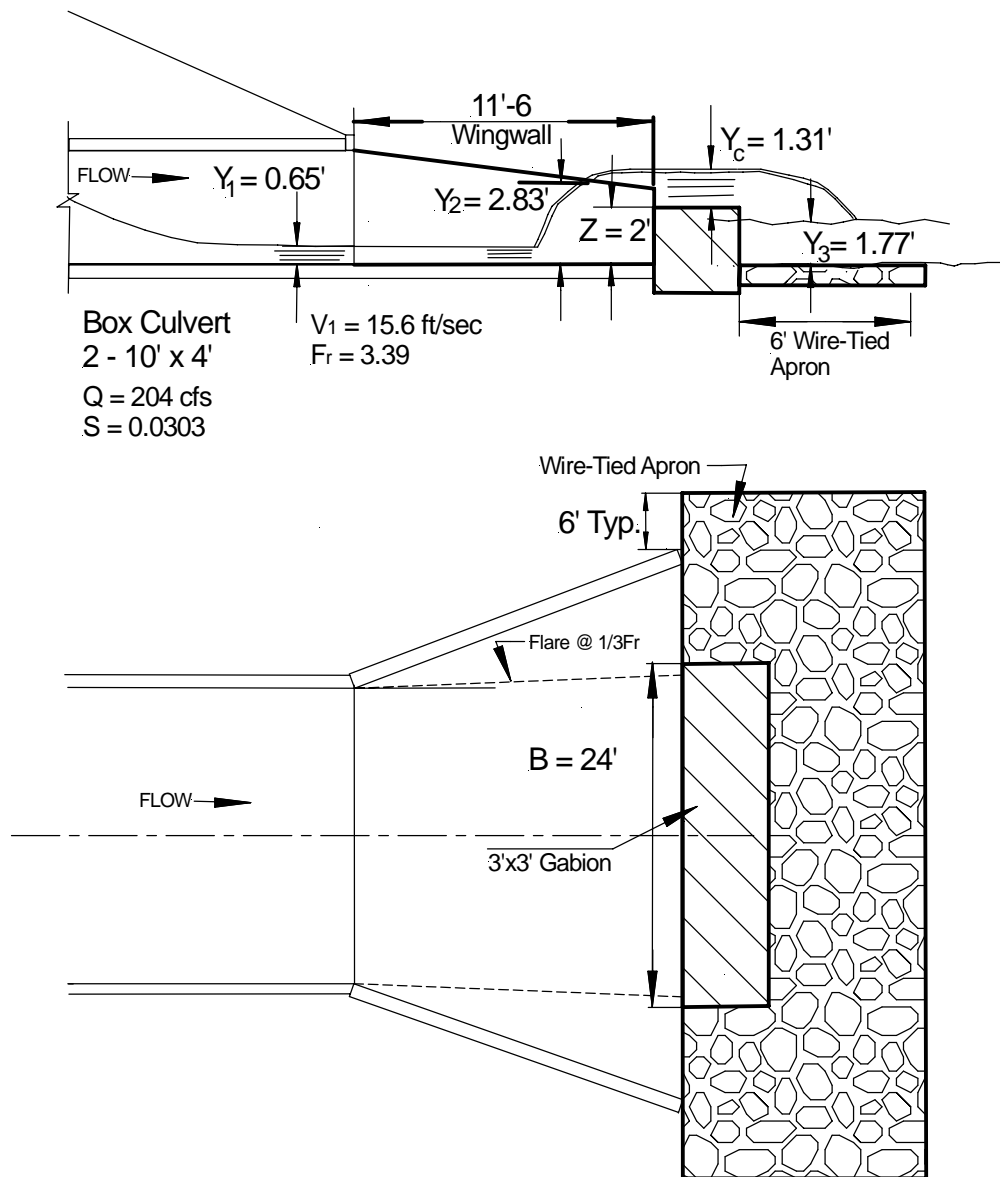


Figure 9-4a, Weir Block layout

9.6 Weir Block Basin (continued)

9.6.3 Design Example

SUBCRITICAL FLOW

Given:

A 2-8x8 box culvert, 0° degree skew with a discharge, Q , of 204 cfs and at a slope of 0.0303
Channel is trapezoidal with 20 feet bottom width and 1.5:1, side slopes, Manning's $n=0.035$, slope=0.008.
Tailwater depth is 1.77 feet.

Step 1 Determine Input Flow parameters:(Q , approach depth, and approach velocity)

Consider providing energy dissipator downstream of concrete apron. Therefore, parameters are at the end of the apron.

At culvert headwall, $Y = 0.76$ Ft., $V = 16.8$ Ft./sec., and $Fr = 3.41$

$$W_b = 16.75 + 2(\cos(20^\circ))(13.0)/3 \cdot 3.41 = 16.75 + 2.42 = 19.17 \text{ Ft.}$$

$$q = Q / W_b = 204 / 19.17 = 10.64 \text{ cfs.}$$

$$Y_1 = 0.67 \text{ Ft., } V_1 = 15.8 \text{ Ft./sec., } Fr = 3.40$$

Step 2 Determine downstream conditions:(depth, Y_3 and velocity)

$$Y_3 = 1.77 \text{ Ft., } V_3 = 5.0 \text{ Ft./sec.}$$

Calculate downstream Froude number

$Fr = 0.70$, downstream flow is subcritical, use an abrupt rise.

Step 3 Determine Alternate Depth

Y_2 , the alternate depth

$$Y_2 = 2.91 \text{ Ft.}$$

Step 4 Size Basin

- a. Determine length of the jump, L_j .

$$L_j = 5 \cdot Y_2 \text{ minimum.}$$

$$L_j = 5 \cdot (2.91) = 14.55 \text{ Ft.}$$

Use 15.0 Ft.

- b. B , the width of the basin perpendicular to flow.

$$\text{Width at end of wingwall} = W_b = 16.75 + 2(\sin(20^\circ))(13.0) = 25.65 \text{ Ft.}$$

Use 26.0 Ft.

9.6 Weir Block Basin (continued)

9.6.3 Design Example (continued)

SUBCRITICAL FLOW (continued)

Step 4 Size Basin(continued)

- c. Determine height of block required, Z ,

$$Z = Y_2 - TW.$$

$$Z = 2.91 - 1.78 = 1.13 \text{ Ft.}$$

$$\text{For Abrupt Rise, Maximum } Z = (F^{5/3})/6 = (3.39^{5/3})/6 = 1.28 \text{ Ft.}$$

$$\text{Use } Z = 1.25 \text{ Ft.}$$

- d. For width B , determine the unit discharge over the weir block, depth, Y , and velocity V .

$$q = Q/B = 204/26.0 = 7.85 \text{ cfs}$$

$$Y = Y_2 - Z$$

$$Y = 2.91 - 1.25 = 1.66 \text{ Ft.}$$

- e. Determine V_B

- Basin exit velocity, $V_B = Q/(W_B)(Y) = (204)/(26.0 \times 1.66) = 4.72 \text{ Ft./sec.}$
- Compare V_B with the average normal flow velocity in the natural channel, V_d .

$$V_d = 5.0 \text{ Ft./sec.}$$

$$V_B/V_d = 4.72/5.0 = 0.95, \text{ OK.}$$

Step 5 Determine length of apron, L_a -

$$= 6 \text{ feet, minimum . USE } 6.0 \text{ Ft.}$$

9.6 Weir Block Basin (continued)

Design Example (continued)

SUBCRITICAL FLOW (continued)

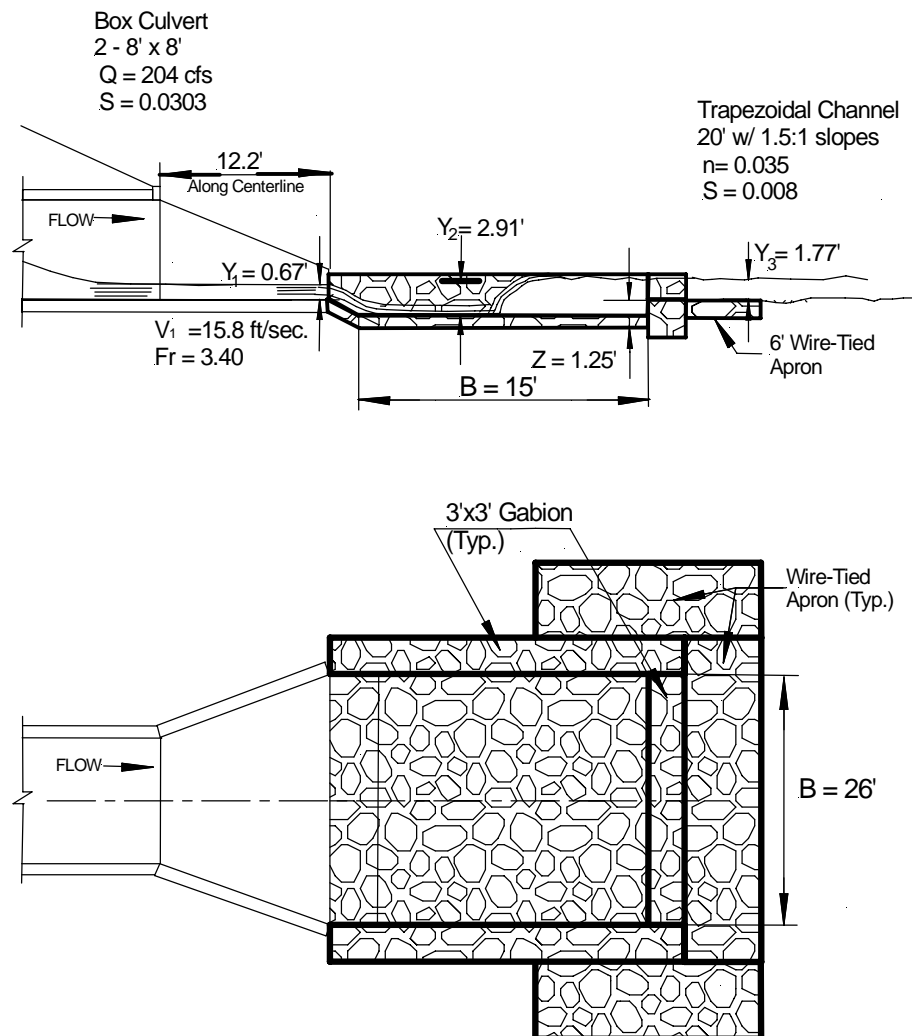


Figure 9-4b, Abrupt Rise Layout

9.7 Impact Basin USBR Type VI

9.7.1 Overview

The USBR Type VI basin, Figure 9-5, was developed by the U.S. Bureau of Reclamation (USBR):

- is referred to as the USBR Type VI basin or hanging baffle,
- is contained in a relatively small box-like structure,
- requires no tailwater for successful performance,
- may be used in open channels as well, and
- is not recommended where debris or ice buildup may cause substantial clogging.

Hanging Baffle

Energy dissipation is initiated by flow striking the vertical hanging baffle and being deflected upstream by the horizontal portion of the baffle and by the floor, creating horizontal eddies.

Notches in Baffle

Notches are provided to aid in cleaning the basin. The notches provide concentrated jets of water for cleaning. The basin is designed to carry the full discharge over the top of the baffle if the space beneath the baffle becomes completely clogged.

Equivalent Depth

This depth must be calculated for a pipe or irregular shaped conduit. The cross section flow area in the pipe is converted into an equivalent rectangular cross section in which the width is twice the depth of flow.

Limitations

Discharges up to 400 cfs per barrel and velocities as high as 50 ft/sec can be used without subjecting the structure to cavitation damage.

Tailwater

A moderate depth of tailwater will improve performance. For best performance, set the basin so that maximum tailwater does not exceed $h_3 + (h_2/2)$.

Slope

If culvert slope is greater than 15° , a horizontal section of at least four culvert widths should be provided upstream.

9.7 Impact Basin USBR Type VI (continued)

9.7.1 Overview (continued)

End Treatment

An end sill with a low-flow drainage slot, 45° wingwalls and a cutoff wall should be provided at the end of the basin.

Apron

An apron of riprap should be placed downstream of the basin for a length of at least four conduit widths.

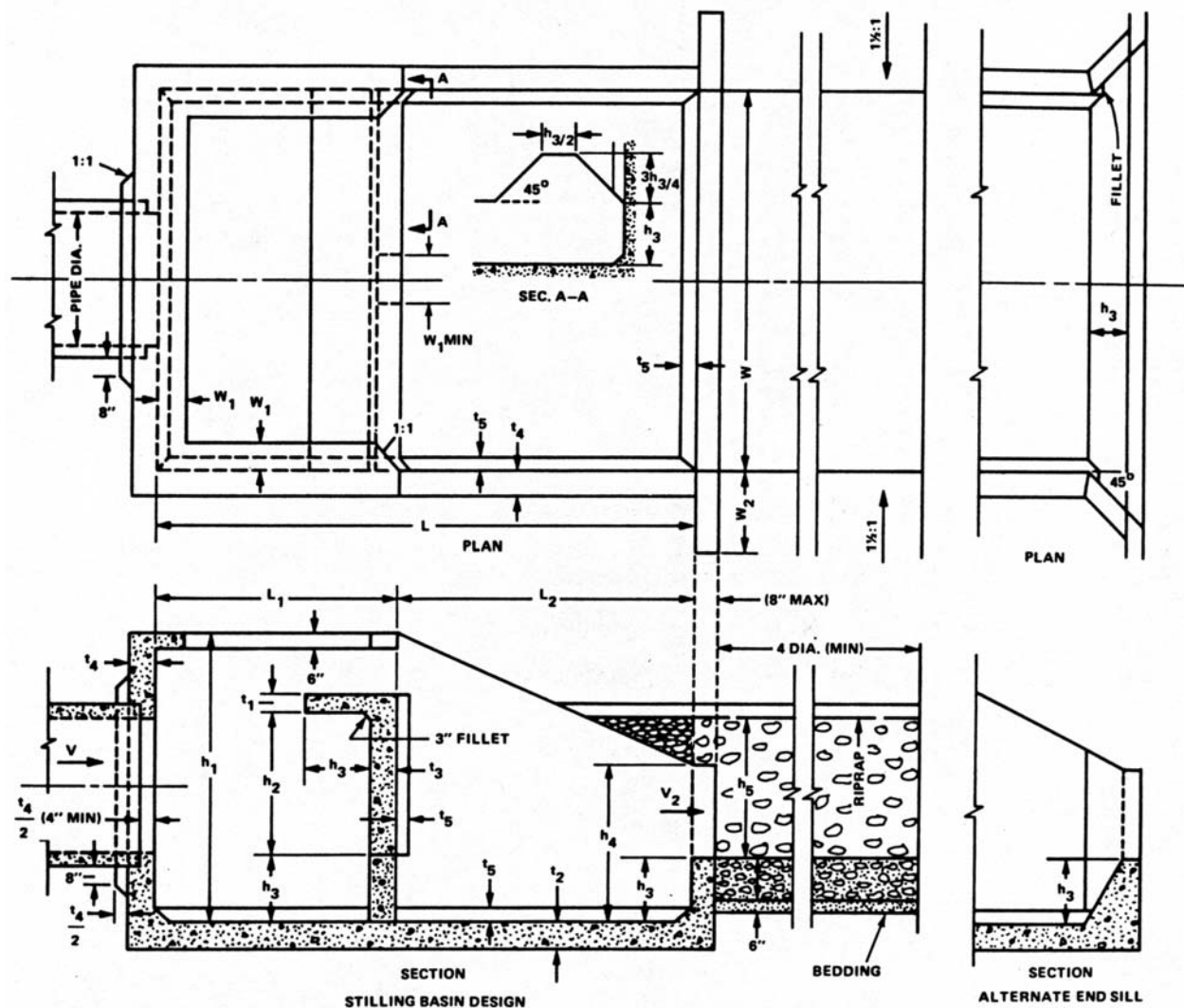


Figure 9-5 USBR Type VI (Impact) Dissipator

9.7 Impact Basin USBR Type VI (continued)

9.7.1 Overview (continued)

Table 9-4 Dimensions Of USBR Type VI Basin

Dimensions in Feet-inches

(See Figure 9-5)

W	h ₁	h ₂	h ₃	h ₄	L	L ₁	L ₂
4	3-1	1-6	0-8	1-8	5-5	2-4	3-1
5	3-10	1-11	0-10	2-1	6-8	2-11	3-10
6	4-7	2-3	1-0	2-6	8-0	3-5	4-7
7	5-5	2-7	1-2	2-11	9-5	4-0	5-5
8	6-2	3-0	1-4	3-4	10-8	4-7	6-2
9	6-11	3-5	1-6	3-9	12-0	5-2	6-11
10	7-8	3-9	1-8	4-2	13-5	5-9	7-8
11	8-5	4-2	1-10	4-7	14-7	6-4	8-5
12	9-2	4-6	2-0	5-0	16-0	6-10	9-2
13	10-2	4-11	2-2	5-5	17-4	7-5	10-0
14	10-9	5-3	2-4	5-10	18-8	8-0	10-9
15	11-6	5-7	2-6	6-3	20-0	8-6	11-6
16	12-3	6-0	2-8	6-8	21-4	9-1	12-3
17	13-0	6-4	2-10	7-1	21-6	9-8	13-0
18	13-9	6-8	3-0	7-6	23-11	10-3	13-9
19	14-7	7-1	3-2	7-11	25-4	10-10	14-7
20	15-4	7-6	3-4	8-4	26-7	11-5	15-4

W	W ₁	W ₂	t ₁	t ₂	t ₃	t ₄	t ₅
4	0-4	1-1	0-6	0-6	0-6	0-6	0-3
5	0-5	1-5	0-6	0-6	0-6	0-6	0-3
6	0-6	1-8	0-6	0-6	0-6	0-6	0-3
7	0-6	1-11	0-6	0-6	0-6	0-6	0-3
8	0-7	2-2	0-6	0-7	0-7	0-6	0-3
9	0-8	2-6	0-7	0-7	0-8	0-7	0-3
10	0-9	2-9	0-8	0-8	0-9	0-8	0-3
11	0-10	3-0	0-8	0-9	0-9	0-8	0-4
12	0-11	3-0	0-8	0-10	0-10	0-9	0-4
13	1-0	3-0	0-8	0-11	0-10	0-10	0-4
14	1-1	3-0	0-8	1-0	0-11	0-11	0-5
15	1-2	3-0	0-8	1-0	1-0	1-0	0-5
16	1-3	3-0	0-9	1-0	1-0	1-0	0-6
17	1-4	3-0	0-9	1-1	1-0	1-0	0-6
18	1-4	3-0	0-9	1-1	1-1	1-1	0-7
19	1-5	3-0	0-10	1-2	1-1	1-1	0-7
20	1-6	3-0	0-10	1-2	1-2	1-2	0-8

9.7 Impact Basin USBR Type VI (continued)

9.7.1 Overview (continued)

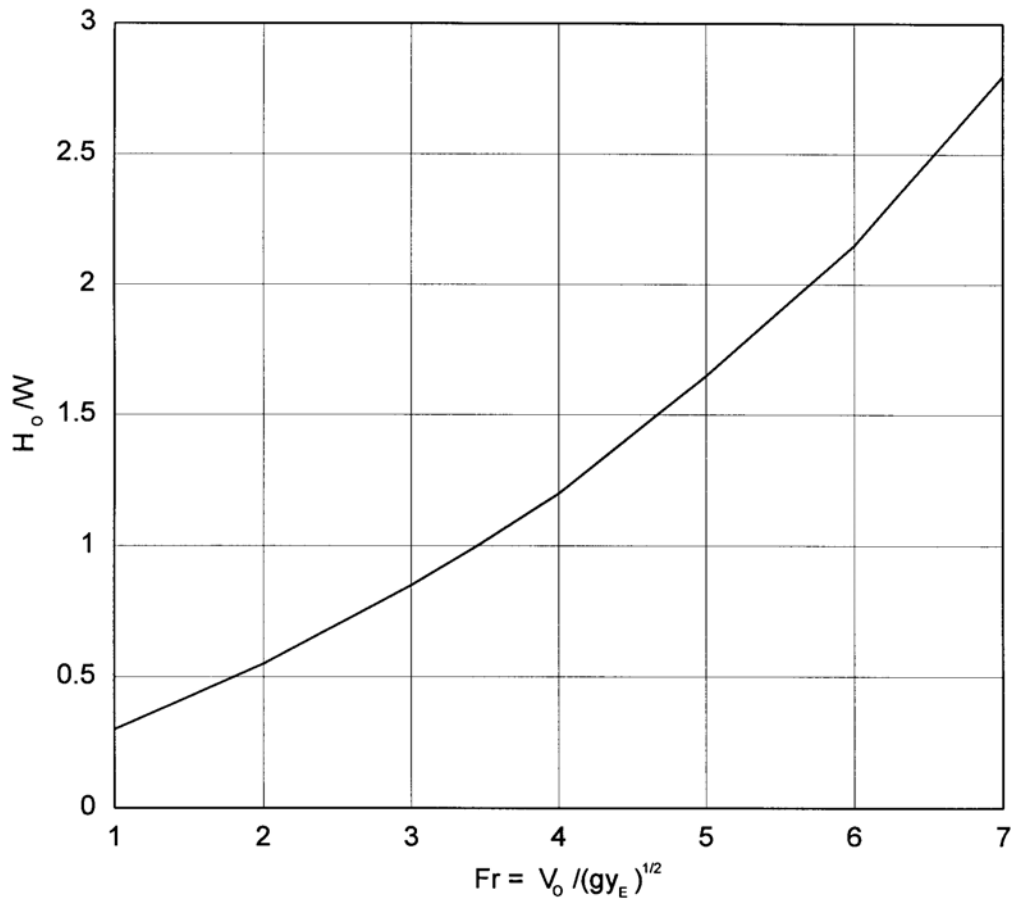


Figure 9-6 Design Curve For USBR Type VI Dissipator

9.7 Impact Basin USBR Type VI (continued)

9.7.1 Overview (continued)

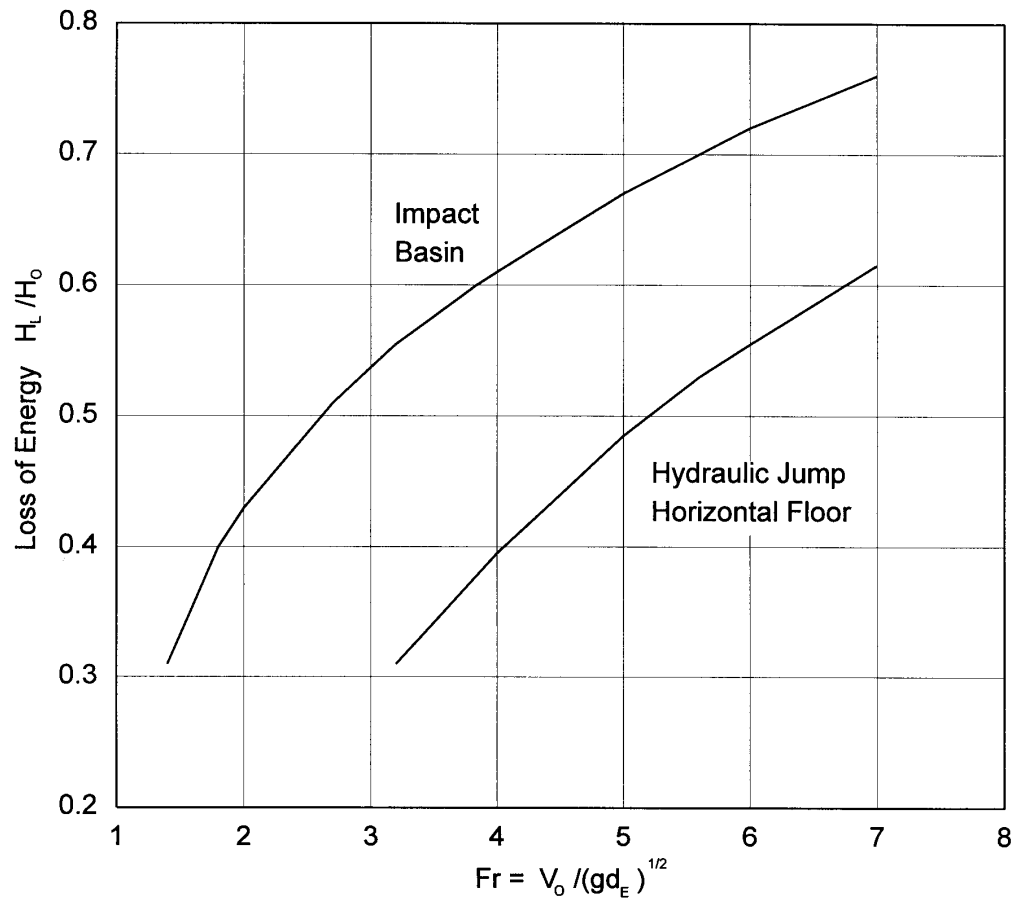


Figure 9-7 Energy Loss For USBR Type VI Dissipator

9.7 Impact Basin USBR Type VI (continued)

9.7.2 Design Procedures

Step 1 Calculate equivalent depth, d_E

- a. Rectangular section, $d_E = d_o = y_o$.
- b. Other sections, $d_E = (A/2)^{0.5}$.

Step 2 Determine Input Flow

- a. Froude number, $Fr = V_o/(gd_E)^{0.5}$.
- b. Specific energy, $H_o = d_E + V_o^2/2g$.

Step 3 Determine Basin Width, W

- a. Use Figure 9-6.
- b. Enter with Fr and read H_o/W .
- c. $W = H_o/(H_o/W)$.

Step 4 Size Basin

- a. Use Table 9-3 and W .
- b. Obtain the remaining dimensions.

Step 5 Energy Loss

- a. Use Figure 9-7.
- b. Enter with Fr and read H_L/H_o .
- c. $H_L = (H_L/H_o)H_o$.

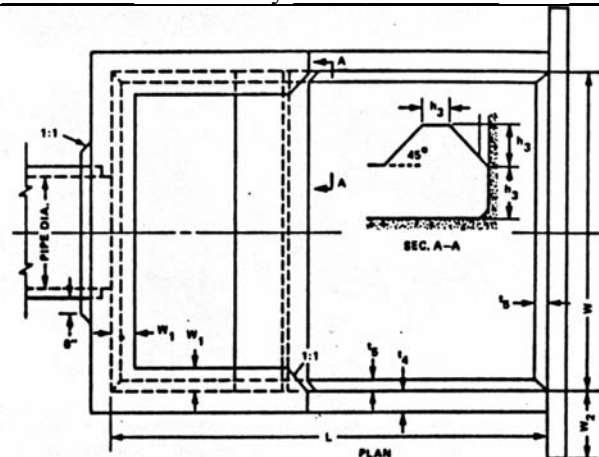
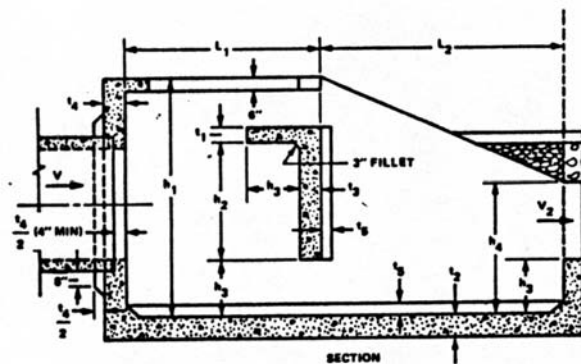
Step 6 Exit Velocity (V_B)

- a. Exit energy (H_E) = $H_o - H_L$.
- b. $H_E = d_B + V_B^2/2g$
 $V_B = (Q/W)/d_B$

9.7 Impact Basin USBR Type VI (continued)

9.7.2 Design Procedures (continued)

Project Name: _____	Project No.: _____
Subject _____	Page ____ of ____
By _____	Date _____ Checked By _____ Date _____



DESIGN DATA: BASIN WIDTH	TRIALS		
	1	2	Final
$d_e = y_e$			
V_o			
$H_o = d_e + V_o^2/2g$			
F_r			
H_o/W			
$W = H_o/(H_o/W)$			

CHECK OUTLET VELOCITY, V_B			
H_L/H_o			
$H_L = (H_L/H_o)H_o$			
$H_L = (H_L/H_o)H_o$			
d_B			
$V_B = (Q/W)/d_B$			
$(H_e)_T = d_B + V_B^2/2g$			
IF $(H_e)_T > H_e$, choose another d_B			

BASIN DIMENSIONS, Feet-inches							
W	h1	h2	h3	h4	L	L1	L2
W	W1	W2	t1	t2	t3	t4	t5

Figure 9-8 USBR Basin Type VI - Design Form

9.7 Impact Basin USBR Type VI (continued)

9.7.3 Design Example

Inputs

D = 48 inch pipe, $S_o = 0.15$ ft/ft, $n = 0.015$

$Q = 300$ cfs, $d_o = 2.3$ ft., $V_o = 40$ ft/s

Step 1 Calculate Equivalent Depth, d_E .

Other sections, $d_E = (A/2)^{0.5}$

$A = Q/V_o = 300/40 = 7.5$ ft²

$d_E = (7.5/2)^{0.5} = 1.94$ ft.

Step 2 Determine Input Flow

a. Froude number, $Fr_o = V_o/(gd_E)^{0.5}$
 $Fr = 40/[32.2(1.94)]^{0.5} = 5.05$

b. Specific energy, $H_o = d_E + V_o^2/2g$
 $H_o = 1.94 + (40)^2/(2)(32.2) = 26.8$ ft.

Step 3 Determine Basin Width, W.

- Use Figure 9-6
- Enter with $Fr = 5.05$ and read $H_o/W = 1.68$
- $W = H_o/(H_o/W) = 26.8/1.68 = 16$ ft.

Step 4 Size Basin

- Use Table 9-3 and W.
- Obtain the remaining dimensions.

Step 5 Energy Loss

- Use Figure 9-7, Impact Basin
- Enter with $Fr = 5.05$ and read $H_L/H_o = 0.67$
- $H_L = (H_L/H_o)H_o = 0.67(26.8) = 18$ ft.

Step 6 Solve Energy Equation for Exit Velocity (V_B)

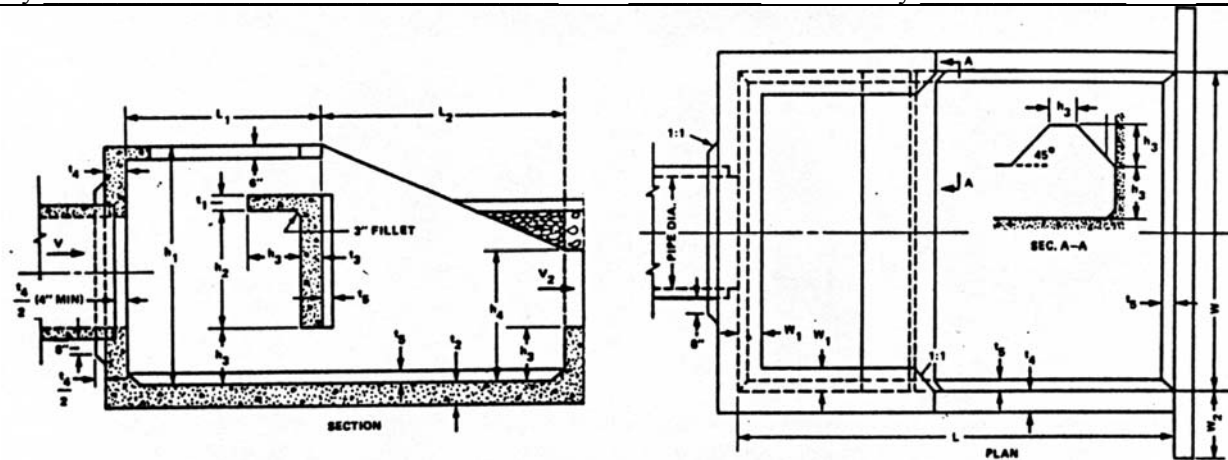
- Exit energy (H_E) = $H_o - H_L = 26.8 - 18 = 8.8$ ft.
- $H_E = d_B + V_B^2/2g = 8.8$ ft
 $V_B = (Q/W)/d_B = (300/16)/d_B = 18.75/d_B$

d_B	V_B	$V_B^2/2g$	$d_B + V_B^2/2g = 8.8$
2.3 = d_c	8.1	1.02	3.3
1.0	18.8	5.49	6.5
0.8	23.4	8.50	9.3
0.9	20.8	6.72	7.6
0.85	22.1	7.58	8.4
0.83	22.6	7.93	8.76 ~ 8.8 use.

9.7 Impact Basin USBR Type VI (continued)

9.7.3 Design Example (continued)

Project Name: <u>Design Example</u>	Project No.: <u>ADT064</u>
Subject <u>USBR Type VI Impact Basin</u>	Page <u>1</u> of <u>1</u>
By _____	Date _____
Checked By _____	Date _____



DESIGN DATA: BASIN WIDTH	TRIALS		
	1	2	Final
$d_e = y_e$	2.3'		
V_o	40		
$H_o = d_e + V_o^2/2g$	26.8'		
F_r	5.1		
H_o / W	1.68		
$W = H_o / (H_o/W)$	16		

CHECK OUTLET VELOCITY, V_B			
H_L/H_o	0.67		
$H_L = (H_L/H_o)H_o$	18'		
$H_e = H_o - H_L$	8.8		
d_B	2.3'	0.9'	0.8'
$V_B = (Q/W)/d_B$	8.1	20.8	23.4
$(H_e)_T = d_B + V_B^2/2g$	3.3'	7.6'	9.3'
IF $(H_e)_T > H_e$, choose another d_B			

BASIN DIMENSIONS, Feet-inches							
W	h_1	h_2	h_3	h_4	L	L_1	L_2
16	12-3	6-0	2-8	6-8	21-4	9-1	12-3
W	W_1	W_2	t_1	t_2	t_3	t_4	t_5
16	1-3	3-0	0-9	1-0	1-0	1-0	0-6

Figure 9-9 USBR Basin Type VI - Design Example

9.7 Impact Basin USBR Type VI (continued)

9.7.4 Computer Results

The dissipator geometry can be computed using the "Energy Dissipator" module that is available in microcomputer program HY-8, Culvert Analysis. The output of the culvert and channel input data, and computed geometry using this module are shown below.

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0			
CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
06-02-1997	16:13:53	ENERGY4	06-02-1997
CULVERT AND CHANNEL DATA			
CULVERT NO. 1		DOWNSTREAM CHANNEL	
CULVERT TYPE: 4 FT CIRCULAR		CHANNEL TYPE: IRREGULAR	
CULVERT LENGTH = 300.0 FT		BOTTOM WIDTH = 7.0 FT	
NO. OF BARRELS = 1.0		TAILWATER DEPTH = 2.5 FT	
FLOW PER BARREL = 300 CFS		TOTAL DESIGN FLOW = 300.0 CFS	
INVERT ELEVATION = 172.5 FT		BOTTOM ELEVATION = 172.5 FT	
OUTLET VELOCITY = 40.0 FPS		NORMAL VELOCITY = 15.9 FPS	
OUTLET DEPTH = 3.94 FT			
USBRTYPE 6 DISSIPATOR — FINAL DESIGN			
BASIN OUTLET VELOCITY = 23.4 FPS			
W = 16.0 FT	W1 = 1.3 FT	W2 = 3.0 FT	
L = 21.3 FT	L1 = 9.1 FT	L2 = 12.3 FT	
H1 = 12.3 FT	H2 = 6.0 FT	H3 = 2.7 FT	
H4 = 6.7 FT	T1 = 0.8 FT	T2 = 1.0 FT	
T3 = 1.0 FT	T4 = 1.0 FT	T5 = 0.5 FT	

9.8 SAF Stilling Basin

9.8.1 Overview

The St. Anthony Falls (SAF) stilling basin uses a forced hydraulic jump to dissipate energy, and:

- is based on model studies conducted by US Soil Conservation Service (SCS) at the St. Anthony Falls (SAF) Hydraulic Laboratory of the University of Minnesota;
- uses chute blocks, baffle blocks and an end sill to force the hydraulic jump and reduce jump length by about 80%;
- is recommended where $Fr = 1.7$ to 17 .

9.8.2 Equations

Basin Width, W_B

- for box culvert $W_B = B =$ Culvert width, ft.
- for pipe, use $W_B =$ Culvert diameter, D , ft, or

$$W_B = 0.54Q/D^{1.5} \quad (9.16)$$

whichever is larger.

Where: $Q =$ discharge, cfs

Flare (1:z)

Flare is optional, if used it should be flatter than 2:1.

Basin Length, L_B

$$Y_2 = 0.5 * Y_1 [(1 + 8 * Fr_1^2)^{0.5} - 1] \quad (9.3)$$

Where: $Y_1 =$ initial depth of water, ft.

$Y_2 =$ sequent depth of jump, ft.

$Fr_1 =$ Froude number entering basin, Fr

$$L_B = 4.5 Y_2 / Fr_1^{0.76} \quad (9.17)$$

9.8 SAF Stilling Basin (continued)

9.8.2 Equations (continued)

Basin Floor

The basin floor should be depressed below the streambed enough to obtain the following depth (d_2) below the tailwater:

- For $Fr_1 = 1.7$ to 5.5

$$d_2 = Y_2[1.1 - (Fr_1^2/120)] \quad (9.18)$$

- For $Fr_1 = 5.5$ to 11

$$d_2 = 0.85 Y_2 \quad (9.19)$$

- For $Fr_1 = 11$ to 17

$$d_2 = Y_2[1.1 - (Fr_1^2/800)] \quad (9.20)$$

Chute Blocks

Height, $h_1 = d_1$

Width, $W_1 = \text{Spacing}, W_1 = 0.75d_1$

Number of blocks = $N_c = W_B/2W_1$, rounded to a whole number

Adjusted $W_1 = W_2 = W_B/2N_c$

N_c includes the 1/2 block at each wall

Baffle Blocks

Height, $h_3 = d_1$

Width, $W_3 = \text{Spacing}, W_4 = 0.75d_1$

Basin width at baffle blocks, $W_{B2} = W_B + 2L_B/3$

Number of blocks = $N_B = W_{B2}/2W_3$, rounded to a whole number

Adjusted $W_3 = W_4 = W_{B2}/2N_B$

Check total block width to insure that 40 to 55% of W_{B2} is occupied by block.

Staggered with chute blocks

Space at wall $\geq 0.38d_1$

Distance from chute blocks (L_{1-3}) = $L_B/3$

End Sill Height, $h_4 = 0.07d_j$

Sidewall Height = $d_2 + 0.33d_j$

Wingwall Flare = 45°

9.8 SAF Stilling Basin (continued)

9.8.3 Design Procedure

The design of a St. Anthony Falls (SAF) basin consists of several steps as follows:

Step 1 Select Basin Type

- a. Rectangular or flared.
- b. Choose flare (if needed), 1:z.
- c. Determine basin width, W_B .

Step 2 Select Depression

- a. Choose the depth d_2 to depress below the streambed, B_d .
- b. Assume $B_d = 0$ for first trial.

Step 3 Determine Input Flow

- a. d_1 and V_1 , using energy equation.
- b. Froude Number, Fr_1

Step 4 Calculate Basin Dimensions

- a. Y_2 (equation 9.8).
- b. L_B (equation 9.9).
- c. d_2 (equation 9.10, 9.11, or 9.12).
- d. $L_S = (d_2 - TW)/S_s$
- e. $L_T = (B_d)/S_T$ (see Figure 9-10).
- f. $L = L_T + L_B + L_S$ (see Figure 9-10).

Step 5 Review Results

- a. If $d_2 \neq (B_d - LS_o + TW)$ return to Step 2.
- b. If approximately equal, continue.

Step 6 Size Elements

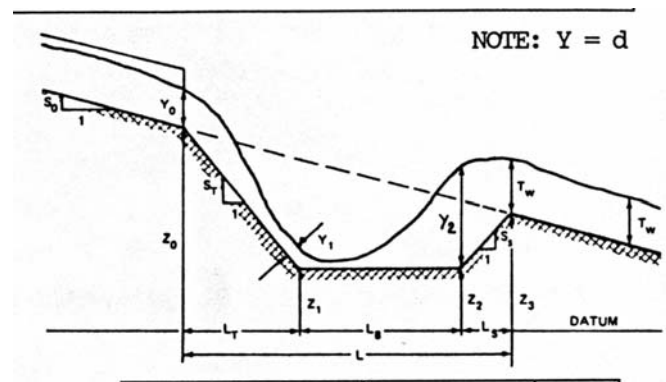
- a. Chute blocks (h_1, W_1, W_2, N_c).
- b. Baffle blocks ($h_3, W_3, W_4, N_B, L_{1-3}$).
- c. End sill (h_4).
- d. Side wall height ($h_5 = d_2 + 0.33d_j$).

9.8 SAF Stilling Basin (continued)

9.8.3 Design Procedure (continued)

SAF Basin			
Project Name: _____	Project No.: _____		
Subject _____	Page ____ of ____		
By _____	Date _____	Checked By _____	Date _____

DATA SUMMARY	TRIALS		
	1	2	3
TYPE			
FLARE (Z:1)			
WIDTH (W_B)			
DEPRESSION (B_d)			
$S_s = S_t$			
DEPTH (d_0)			
VELOCITY (V_0)			
$B_d + d_0 + V_0^2/2g$			
DEPTH (d_1)			
$d_1 + V_1^2/2g$			
Fr_1			
D_j			
L_B			
D_2			
L_S			
$L_T = (B_d)/S_T$			
$L = L_T + L_B + L_S$			
$B_d - LS_0 + TW = d_2$			



Dimensions	TRIALS		
H_1 , Chute Block	1	2	Final
W_1			
N_c			
W_2			
H_3 , Baffle Block			
W_3			
W_4			
N_B			
H_4 , End Sill			
H_5 , Side Wall			

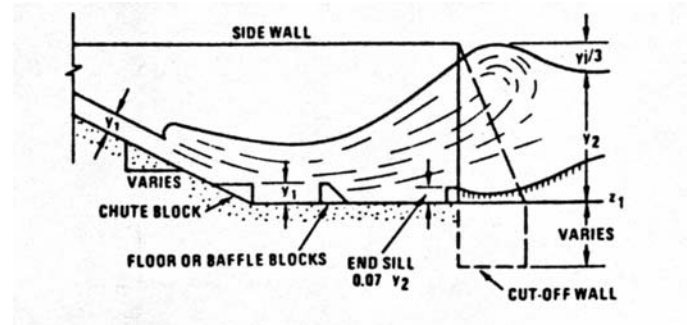


Figure 9-10 - St. Anthony Falls Basin Checklist

9.8 SAF Stilling Basin (continued)

9.8.4 Design Example

- See Section 9.5.2 for input values.
- See Figure 9-12 for completed computation form.

Step 1 Select Basin Type

- Use rectangular
- No flare
- Basin width, $W_B = 7$ ft., unit discharge = $400/7 = 57.1$ cfs

Step 2 Select Depression

Trial 1 $B_d = 8$ ft., $S_s = S_t = 1$

Step 3 Determine Input Flow

Trial 1

- Energy equation (culvert to basin):

$$\text{Culvert outlet} = B_d + d_o + V_o^2/2g = 8 + 1.8 + (32)^2/(2 \times 32.2) = 25.7 \text{ ft.}$$

$$\text{Basin floor} = 0 + d_1 + V_1^2/2g$$

$$\text{Solve: } 25.7 = d_1 + V_1^2/2g$$

$$\text{Velocity} = V_1 = q/d_1$$

d_1	V_1	$V_1^2/2g$	$d_1 + V_1^2/2g$
1.5	38	22.4	$24 < 25.7$
1.4	41	26.1	$27.5 > 25.7$, Use.

$$\text{b. } Fr_1 = 41/(1.4 \times 32.2)^{0.5} = 6.1$$

Step 4 Calculate Basin Dimensions

Trial 1

- $d_j = 11.4$ ft. (equation 9.8)
- $L_B = 13.0$ ft. (equation 9.9)
- $d_2 = 9.7$ ft. (equation 9.10)
- $L_S = (d_2 - TW)/S_s = (9.7 - 2.8)/1 = 6.9$ ft.
- $L_T = (B_d)/S_T = 8/1 = 8$ ft.
- $L = L_T + L_B + L_S = 8 + 13 + 7 = 28$ ft.

Step 5 Review Results

Trial 1

- If d_2 does not equal $(B_d - LS_o + TW)$, then adjust drop
 $9.7 \neq (8 - 28(0.05) + 2.8) = 9.4$ ft.
- Add $(9.7 - 9.4) = 0.3$ ft. more drop and return to Step 2.

9.8 SAF Stilling Basin (continued)

9.8.4 Design Example (continued)

Step 2 Select Depression

Trial 2

$$B_d = 8.3 \text{ ft.}, S_S = S_T = 1$$

Step 3 Determine Input Flow

Trial 2

- a. Energy equation (culvert to basin):
 Culvert outlet = $B_d + d_o + V_o^2/2g = 8.3 + 1.8 + (32)^2/2g = 26 \text{ ft.}$
 Basin floor = $0 + d_1 + V_1^2/2g$
 Solve: $26 = d_1 + V_1^2/2g$
- | | | | |
|-------------------|------------------|-------------------------|--|
| $\frac{d_1}{1.4}$ | $\frac{V_1}{41}$ | $\frac{V_1^2/2g}{26.1}$ | $\frac{d_1 + V_1^2/2g}{27.5 \approx 26, \text{ Use.}}$ |
|-------------------|------------------|-------------------------|--|

b. $Fr_1 = 41/(1.4 \times 32.2)^{0.5} = 6.1$

Step 4 Calculate Basin Dimensions

Trial 2

- a. $d_j = 11.4 \text{ ft}$ (equation 9.8)
 b. $L_B = 13.0 \text{ ft.}$ (equation 9.9)
 c. $d_2 = 9.7 \text{ ft.}$ (equation 9.10)
 d. $L_S = (d_2 - TW)/S_S = 6.9 \text{ ft.}$
 e. $L_T = (B_d)/S_T = 8.3/1 = 8.3 \text{ ft.}$
 f. $L = L_T + L_B + L_S = 8.3 + 13 + 7 = 28.3 \text{ ft.}$

Step 5 Review Results

Trial 2

- a. $d_2 = 9.7 \approx (8.3 - 28.3(0.05) + 2.8) = 9.7 \text{ ft.}$ Is approximately equal, continue.

Step 6 Size Elements

Trial 2

- a. Chute blocks (h_1, W_1, W_2, N_c)
 $h_1 = d_1 = 1.4 \text{ ft.}$
 $W_1 = 0.75d_1 = 1.0 \text{ ft}$
 $N_c = W_B/2(W_1) = 7/2(1) = 3.5$, use 4
 Adjusted $W_1 = 7/2(4) = 0.9 \text{ ft} = W_2$
 Use 3 full blocks, 4 spaces and a half of block at each wall.
- b. Baffle blocks ($h_3, W_3, W_4, N_B, L_{1-3}$)
 $h_3 = d_1 = 1.4 \text{ ft.}$
 $W_3 = 0.75d_1 = 1 \text{ ft.}$
 Use 4 blocks, and adjusted as above $W_3 = W_4 = 0.9 \text{ ft.}$
 $L_{1-3} = L_B/3 = 13/3 = 4.3 \text{ ft.}$

9.8 SAF Stilling Basin (continued)**9.8.4 Design Example (continued)**

- c. End sill (h_4) = $0.07d_j = 0.07(11.4) = 0.8$ ft
- d. Side wall height (h_s) = $d_2 + 0.33d_j = 9.7 + 0.33(11.4) = 13.5$ ft.

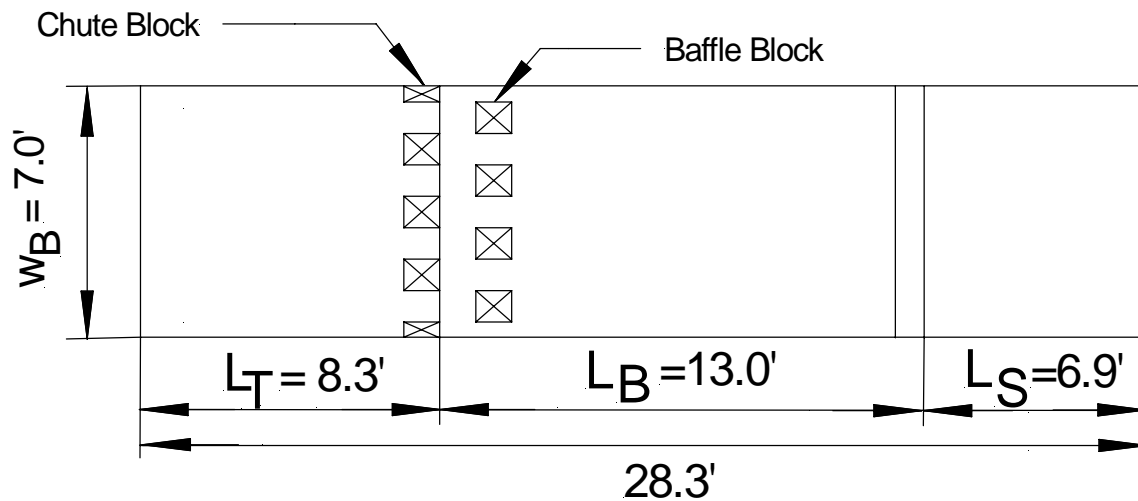


Figure 9-11 SAF Stilling Basin - Design Example

9.8 SAF Stilling Basin (continued)

9.8.5 Computer Results

The dissipator geometry can be computed using the "Energy Dissipator" module, which is available in microcomputer program HY-8, Culvert Analysis. The output of the culvert and channel input data, and computed geometry using this module are shown below.

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
09-19-1996	15:26:05	CHPTR9A	09-19-1996

CULVERT AND CHANNEL DATA

CULVERT NO. 1	DOWNSTREAM CHANNEL
CULVERT TYPE: 7.0 x 6.0 BOX	CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 300.0 FT	BOTTOM WIDTH = 7.0 FT
NO. OF BARRELS = 1.0	TAILWATER DEPTH = 2.8 FT
FLOW PER BARREL = 400.0 CFS	TOTAL DESIGN FLOW = 400.0 CFS
INVERT ELEVATION = 172.5 FT	BOTTOM ELEVATION = 172.5 FT
OUTLET VELOCITY = 31.3 FPS	NORMAL VELOCITY = 17.5 FPS
OUTLET DEPTH = 2.02 FT	

ST. ANTHONY FALLS BASIN -- FINAL DESIGN

LB = 11.9 FT	LS = 5.8 FT	LT = 7.1 FT
L = 24.8 FT	Y1 = 1.3 FT	Y2 = 8.7 FT
Z1 = 165.4 FT	Z2 = 165.4 FT	Z3 = 171.3 FT
WB = 8.2 FT	WB3 = 8.2 FT	

----- CHUTE BLOCKS -----

H1 = 1.3 FT	W1 = 1.0 FT	W2 = 1.0 FT	NC = 4.0
-------------	-------------	-------------	----------

----- BAFFLE BLOCKS -----

W3 = 1.0 FT	W4 = 1.0 FT	NB = 4.0
H3 = 1.3 FT	LCB = 4.0 FT	

----- END SILL -----

H4 = 0.7 FT

BASIN OUTLET VELOCITY = 17.5 FPS

9.9 Straight Drop Stilling Basin

9.9.1 Overview

The Straight Drop Stilling basin uses a vertical drop and is rectangular shaped to develop a forced hydraulic jump to dissipate energy:

- was developed for **subcritical** approach flow
- is effective for drop height ratios, $H/Y_c \leq 15$ provided the approach width, B is $\geq 1.5 Y_c$
- requires a tailwater of at least $2.15 Y_c$
- uses a row of blocks and an end sill to force the hydraulic jump

The Straight drop-stilling basin has been used for supercritical flow by using the normal depth or the drawdown depth for the depth at the brink. For supercritical flow, the basin should be greater than determined from figure 9-13.

9.9.2 Equations

Basin Width, W_B

- for box culvert $W_B = B =$ Culvert width, ft.
- for pipe, use $W_B =$ Culvert diameter, D , ft, or

$$W_B = 0.54Q/D^{1.5} \quad (9.16)$$

whichever is larger.

Where: Q = discharge, cfs

Batter

Batter is optional, if used it should be no flatter than 1:1.

Basin Length, L_b

$$L_b = L_A + L_B + L_c \quad (9.21)$$

L_A = drop length, figure 9-19

$$L_B = 0.8 Y_c$$

$$L_c = 2.15 Y_c$$

$$Y_2 = 0.5 * Y_1 [(1 + 8 * Fr_1^2)^{0.5} - 1] \quad (9.3)$$

Where: Y_1 = initial depth of water, ft.

Y_2 = sequent depth of jump, ft.

Fr_1 = Froude number entering basin, Fr

9.9 Straight Drop Stilling Basin (continued)

9.9.2 Equations (continued)

Basin Floor

The basin floor should be depressed below the streambed enough to obtain the following depth (Y_3) below the tailwater:

$$Y_3 = 2.15 Y_c \quad (9-22)$$

Baffle Blocks

$$\text{Height, } h_B = 0.8 * Y_c \quad (9-23)$$

$$\text{Width, } b_B = (0.4 \pm 0.15) * Y_c \text{ so that blockage is about 50\%.} \quad (9-24)$$

Basin width at baffle blocks, W_B

Number of blocks = $N_B = W_B / b_B$, rounded to a whole number

Adjusted $b_B = W_B / 2N_B$

Check total block width to insure that 40 to 55% of W_B is occupied by block.

Space at wall $\geq 0.38d_1$

End Sill Height,

$$h_4 = 0.4 * Y_c \quad (9-25)$$

Sidewall Height

$$= 0.85 * Y_c \text{ above tailwater level} \quad (9-26)$$

$$= 2.4 * Y_c \text{ to } 3.0 * Y_c$$

Wingwall Flare = 45°

9.9.3 Design Procedure

The design of a straight drop stilling basin consists of several steps as follows:

Step 1 Determine Input Flow

- a. d_1 and V_1 .
- b. Froude Number, Fr_1
- c. Calculate Specific Head, $H = y_o + V_o^2 / 2g$
- d. Calculate Critical Depth, $y_c = 2H / 3$

9.9 Straight Drop Stilling Basin (continued)

9.9.3 Design Procedure (continued)

Step 2 Select Basin Dimensions

- a. Determine basin width, W_B
- b. Calculate the minimum depth of pool, $Y_3 = 2.15 Y_c$
- c. Calculate the distance to tailwater, h_2 . In figure 9-13, the crest is the datum, i.e., tailwater below the crest is a negative number. (h_2 = distance from crest to floor – depth of water on floor.)

Step 3 Calculate Minimum Length of Basin

$$L_b = L_1 + L_2 + L_3$$

L_A = drop length, Figure 9-13

$$L_2 = 0.8 Y_c$$

$$L_3 = 1.75 Y_c$$

Step 4 Calculate Size of Blocks

- a. Baffle blocks (h_B , b_B , N_B).

$$\text{Height, } h_B = 0.8 * Y_c$$

Width, $b_B = (0.4 \pm 0.15) * Y_c$ so that blockage is about 50%.

Basin width at baffle blocks, W_B

Number of blocks = $N_B = W_B / 2b_B$, rounded to a whole number

Adjusted $b_B = W_B / 2N_B$

Check total block width to insure that 50% to 60% of W_B is occupied by block.

Space at wall $\geq 0.38d_1$

- b. End sill (h_4).

$$h_4 = 0.4 * Y_c$$

Step 5 Sidewall Height

= $0.85 * Y_c$ above tailwater level

= $2.4 * Y_c$ to $3.0 * Y_c$

9.9 Straight Drop Stilling Basin (continued)

9.9.3 Design Procedure (continued)

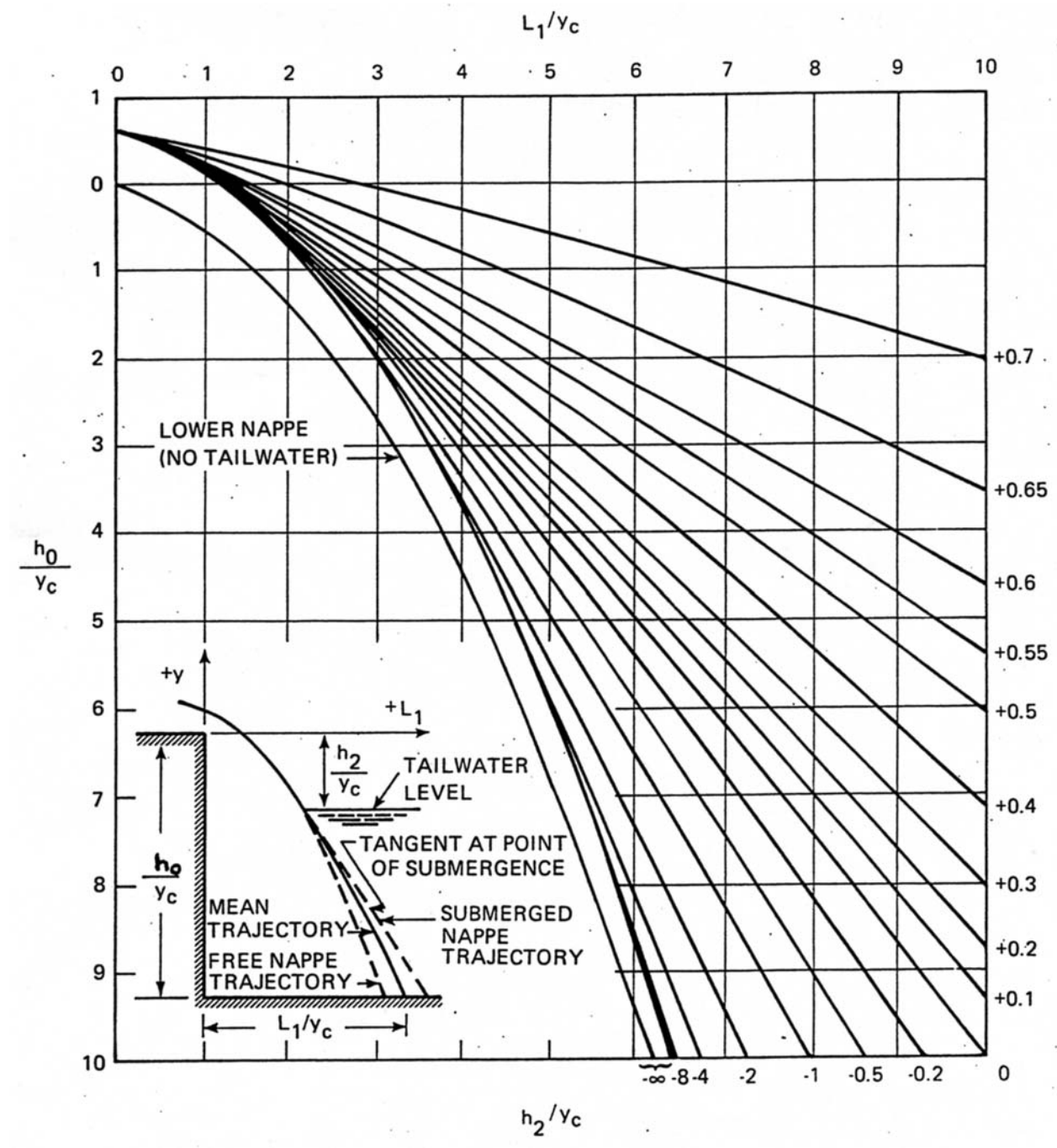


Figure 9-13 Determination of L_1 for Straight Drop Stilling Basin.

9.9 Straight Drop Stilling Basin (continued)

9.9.3 Design Procedure (continued)

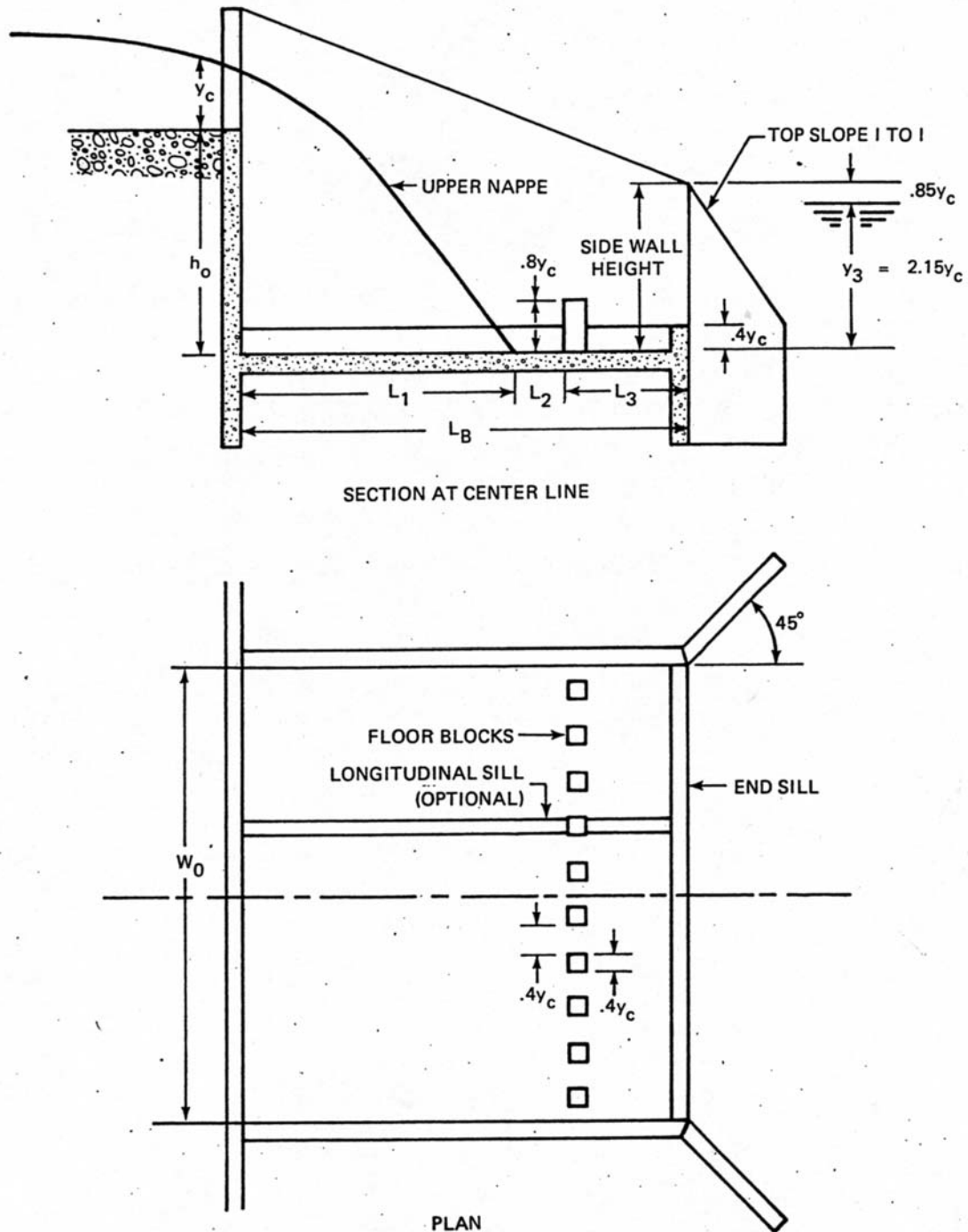


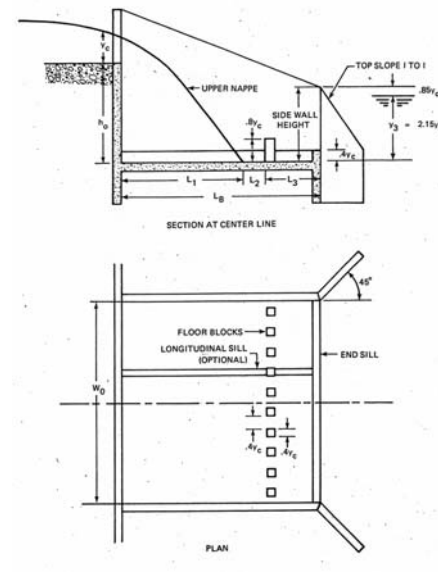
Figure 9-14 Layout of Drop Stilling Basin

9.9 Straight Drop Stilling Basin (continued)

9.9.3 Design Procedure (continued)

Straight Drop Stilling Basin			
PROJECT: _____	PROJECT NO.: _____		
SUBJECT _____	PAGE _____	OF _____	
BY _____	DATE _____	DATE _____	
CHECKED BY _____	DATE _____		

Straight Drop Stilling Basin DESIGN VALUES	TRIAL	
	1	2
Discharge, cfs		
Approach slope		
Manning's n		
Approach Depth, (d ₁)		
Approach Velocity, V ₁		
Specific Head, d ₁ +V ₁ ² /2g		
Critical Depth, Y _c		
Approach Froude No, Fr ₁		
Sequent Depth, Y ₂		
Drop, Crest to channel Invert		
WIDTH (W _B)		
Minimum depth of Pool, Y ₃		
Distance to tailwater, h ₂		
h ₀ = h ₂ - Y ₃		
Z, depth below channel invert, Drop+ h ₀		
h ₀ / Y _c		
h ₂ / Y _c		
L ₁ / Y _c , Fig 9-19		
L ₁		
L ₂ = 0.8 Y _c		
L ₃ >= 1.75 Y _c		
L _B = L ₁ + L ₂ + L ₃		



DIMENSIONS OF ELEMENTS	TRIAL		
	1	2	FINAL
Baffle Bocks			
$h_B = 0.8 Y_c$			
$b_B = 0.4 Y_c$			
Spacing			
$NB = W_B/2 b_B$			
H_E , END SILL, $0.4 Y_c$			
H_{SW} , SIDEWALL, $3 Y_c$			

Figure 9-15 Straight Drop Stilling Basin Form

9.9 Straight Drop Stilling Basin (continued)

9.9.4 Design Example

- See Section 9.6 for input values.
- See Figure 9-15 for computation form.

Step 1 Determine Input Flow Parameters

Approach and downstream channel, trapezoidal with $b=10'$ Side slopes 3:1
 $S_o=0.002$, $n=0.03$

$Q=250$ cfs, Drop from crest to invert of downstream channel=6.0 feet

a. Y_o and V_o .

$Y_o=3.36$ ft $V_o=3.7$ fps

Therefore drop to tailwater is $6.0-3.36 = 2.64$ ft.

b. Froude Number, Fr_1

$$Fr_1 = V_o / (g * Y_o)^{0.5} = 0.44$$

c. Calculate Specific Head, H

$$H = Y_o + V_o^2 / 2g = 3.36 + (3.7)^2 / (2 * 32.2) = 3.57 \text{ ft.}$$

d. Calculate Critical Depth, Y_c

$$Y_c = 2H/3 = 2 * 3.57 / 3 = 2.38 \text{ ft}$$

Step 2 Select Basin Dimensions

a. Determine basin width, W_B

Use approach channel top width, $10 + 2 * 3 * 3.36 = 30.16$

b. Calculate the minimum depth of pool,

$$Y_3 = 2.15 Y_c = 2.15 * 2.38 = 5.12 \text{ ft}$$

c. Calculate the distance to tailwater, h_2 .

$h_2 = -(\text{distance from crest to channel invert} - \text{depth of water on downstream channel.})$

$$h_2 = -(6.00 - 3.36) = -2.64$$

9.9 Straight Drop Stilling Basin (continued)

9.9.4 Design Example (continued)

Step 2 Select Basin Dimensions (continued)

d. Calculated distance from crest to floor: h_0

$$h_0 = h_2 - Y_3$$

$$h_0 = -2.64 - 5.12 = -7.76 \text{ ft.}$$

Therefore, the floor of the stilling basin is 1.76 feet below the grade line of the downstream channel.

Step 3 Calculate Minimum Length of Basin

$$L_b = L_1 + L_2 + L_3 \quad (9.9)$$

L_1 = drop length, Figure 9-13, Need ratios h_0/Y_c and h_2/Y_c .

$$h_0/Y_c = -7.76/2.38 = -3.26$$

$$h_2/Y_c = -2.64/2.38 = -1.11$$

from Figure 9-13,

$$L_1/Y_c = 3.95$$

$$L_1 = 3.95 * (2.38) = 9.4 \text{ ft.}$$

$$L_2 = 0.8 Y_c = 0.8(2.38) = 1.9 \text{ ft}$$

$$L_3 = 1.75 Y_c = 1.75(2.38) = 4.2 \text{ ft}$$

$$L_b = L_1 + L_2 + L_3 = 9.4 + 1.9 + 4.2 = 15.5 \text{ ft.}$$

Step 4 Calculate Size of Blocks

a. Baffle blocks (h_b , b_b , N_B).

$$\text{Height, } h_b = 0.8 * Y_c = 0.8(2.38) = 1.90 \text{ ft.}$$

$$\text{Width, } b_b = 0.4 * Y_c = 0.4(2.38) = 0.95 \text{ ft, use 1.0 ft.}$$

$$\begin{aligned} \text{Number of blocks} &= N_B = W_B / 2b_b, \\ &= 20 / 2 * 1 = 10 \end{aligned}$$

$$\text{spacing} = (20 - 10 * 1) / 10 = 1 \text{ ft.,}$$

set spacing at wall to be one-half of normal spacing.

9.9 Straight Drop Stilling Basin (continued)**9.9.4 Design Example (continued)**Step 4 Calculate Size of Blocks (continued)

b. End sill (h_4).

$$h_4 = 0.4 * Y_c = 0.4(2.38) = 0.95$$

Step 5 Sidewall Height

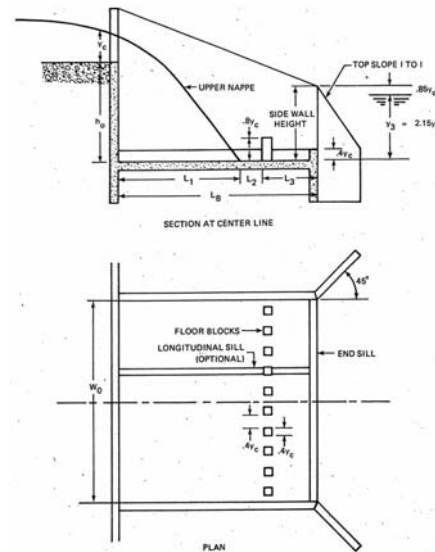
$$= 0.85 * Y_c \text{ above tailwater level}$$

$$= 0.85(2.38) + 3.36 = 1.9 + 3.36 = 5.26 \text{ ft above channel invert.}$$

9.9 Straight Drop Stilling Basin (continued)**9.9.4 Design Example (continued)**

Straight Drop Stilling Basin			
PROJECT: _____	PROJECT NO.: _____		
SUBJECT _____	PAGE _____	OF _____	
BY _____	DATE _____	DATE _____	
CHECKED BY _____	DATE _____		

Straight Drop Stilling Basin DESIGN VALUES	TRIALS	
	1	2
Discharge, cfs	250	
Approach slope	0.002	
Manning's n	0.03	
Approach Depth, (d_1)	3.36	
Approach Velocity, V_1	3.7	
Specific Head, $d_1 + V_1^2/2g$	3.57	
Critical Depth, Y_c	2.38	
Approach Froude No, Fr_1	0.44	
Sequent Depth, Y_2		
Drop; Crest to channel Invert	6.0	
WIDTH (W_B)	30.16	
Minimum depth of Pool, Y_3	5.12	
Distance to tailwater, h_2	-2.64	
$h_0 = h_2 - Y_3$	-7.76	
Z, depth below channel invert, Drop+ h_0	-1.76	
h_0 / Y_c	-3.26	
h_2 / Y_c	-1.11	
L_1 / Y_c , Fig 9-19	3.95	
L_1	9.4	
$L_2 = 0.8 Y_c$	1.9	
$L_3 \geq 1.75 Y_c$	4.2	
$L_B = L_1 + L_2 + L_3$	15.5	



DIMENSIONS OF ELEMENTS	TRIALS		
	1	2	FINAL
Baffle Blocks			
$h_B = 0.8 Y_c$	1.9		1.9
$b_B = 0.4 Y_c$	0.95		1
Spacing	0.95		1
$NB = W_B/2 b_B$	15.87		15
H_E , END SILL, $0.4Y_c$	0.95		1
H_{SW} , SIDE WALL, $3Y_c$	7.14		7

Figure 9-16 Straight Drop Stilling Basin Form, Example

9.10 References

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Appendix A.**Pipe Characteristics:**

Diameter, inches	Area, Ft ²	Perimeter, Ft.	Hydraulic Radius, Ft.
24	3.14	6.28	0.500
30	4.91	7.85	0.625
36	7.07	9.42	0.750
42	9.62	11.00	0.875
48	12.57	12.57	1.00
54	15.90	14.14	1.125
60	19.63	15.71	1.25
66	23.76	17.28	1.375
72	28.27	18.85	1.50